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JANUARY 2019

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MARK HANSON

ON THE COVER

The past year brought exciting astronomical stories that light up the cosmos, just like this portion of the Veil Nebula in Cygnus.

FEATURES

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IN EVERY ISSUE

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FROM THE **EDITOR**

BY DAVID J. EICHER

Hot stories of the cosmos

One of the most exciting aspects of astronomy is that the most amazing discoveries usually are unexpected.

Our annual special feature, "Top 10 Space Stories," continues our tradition of investigating the biggest stories of the year. *Astronomy* magazine alumna Liz Kruesi, a freelance science writer in Texas, has once again compiled this look at an array of discoveries.

The top story this year? In late 2017, a team led by physicist Francis Halzen, who directs the IceCube neutrino detector in Antarctica, discovered one of these elusive particles. When the neutrino passing through Earth interacted with thick ice, the IceCube team noted the particulars, and the event corresponded with an active galaxy. The source, the first outside our galaxy, was observed with the Fermi Gamma-ray Space Telescope. The team concluded this after researching past events, and identified the galaxy as an object 4 billion light-years away. This case of "multi-messenger astronomy" combined data from several sources and marked an exciting moment in astronomical detective work.

We also present lots of other tales. Among them is the tale of the interloping comet, 'Oumuamua, which was detected in late 2017. Discovered with the Pan-STARRS Telescope in Hawaii, this strange cigar-shaped rock was thought to be an asteroid passing through from another solar system. And then, more recently, astronomers detected outgassing from the object, placing it into the class of comets.

The most amazing discoveries usually are unexpected.

The Mars Express spacecraft, armed with its powerful onboard radar, has collected data on a particularly intriguing region of Mars for a number of years and through many orbits. Over the past few years, the spacecraft has passed over the south polar ice cap 30 times, collecting overlapping strips of radar data. The result? Based on sophisticated computer modeling coupled with that data, the planet appears to harbor a subsurface lake. The body of water lying under the ice must be at least 3 feet deep, the scientists believe.

Many more exciting stories are underway. Several years ago, the European Space Agency launched the Gaia mission to map the precise positions and motions of more than 1 billion objects in the sky. The recent data release has lit up the world of astronomy. Hundreds of papers have appeared based on this information, which increases the precision of components of our galaxy dramatically. Precise positions of objects, along with distances to many, have been the focus of this data release. Subsequent production will also focus on photometry and spectroscopy, and the spacecraft can even detect the brightest stars in nearby galaxies.

So much is happening in the world of astronomy these days. Take a moment to catch up on these and other exciting stories. Don't let the cosmos pass you by!

Yours truly,

David J. Eicher
Editor

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Moon Surface | Taken with: ETX125 using the LPI-G
Photo by: Greg Hogan

Jupiter | Taken with: ETX90 using the LPI-G Color
Photo by: Steve Walkenshaw

UNLEASH THE ASTROPHOTOGRAPHER IN YOU!

LUNAR, PLANETARY IMAGER AND GUIDER

Add the perfect accessory to your scope with the Lunar, Planetary Imager and Guider (LPI-G). With our solar, lunar and planetary guide camera, experience the universe on a whole new level! The LPI-G is an excellent camera for solar system astrophotography. Easily capture images of the Moon and planets with this new CMOS camera. The LPI-G is also ideal for capturing images of the Sun* or for use as a standalone auto-guider camera**.

The LPI-G features a 1280 x 960-pixel CMOS AR130 sensor, available in both color and monochrome, with the ability of capturing 28 frames per second at full resolution. This camera has a USB 2.0 connection and ST-4 guider port for easy connection to the mount. Accessories include USB 2.0 cable, ST-4 guide cable, a C-mount, a 1.25" nosepiece, ASCOM drivers, and Meade Sky Capture software CD.

* Proper solar filter is required when imaging the sun.
** ETX Observer does not contain an auto-guider port necessary for use with the LPI-G auto-guiding feature.

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A flat-out explanation

My mind is still boggling over “What shape is space-time?” on p. 34 of the August 2018 issue. In five lucid paragraphs and three diagrams, Alison Klesman explains why, on current evidence, space-time appears to be flat, and how a triangle’s angles indeed sum, in real space, to 180°. Thanks for the revelation! **— Robert Graber,** Kirksville, MO

Stellar starlings

Jeff Hester’s articles are both insightful and thought provoking, and are always the ones I look forward to. Thus, I was pleasantly surprised when I found in the July 2018 issue his entry, “A murmuration of starlings.” This article touched me because recently, I had the pleasure of raising an orphaned starling chick to adulthood and witnessed firsthand what an amazing species of bird they are. Widely considered a pest, they are anything but to me and others who know them. Graceful flight patterns are only one of the talents of this beautiful and unique bird. Their powers of mimicry are legendary, with human words being well within their vocabulary! It is great that the magazine finally made mention of these iconic creatures, and I hope that others reading this might start appreciating them. After all, they share this blue marble of ours spinning through the vast cosmos. **— Naeem England,** Nakusp, British Columbia

An underestimated instrument

With all of your emphasis on encouraging telescopic Mars observation around this year’s opposition, please point out in the future something that I’ve noticed over the years: As Mars oppositions approach perihelion, those with quality binoculars can see the planet as a tiny but distinct disk around sunrise and roughly a half-hour before, and around sunset and roughly a half-hour after. During these brief periods, quality binoculars show Mars as a tiny disk — appearing how Jupiter’s Galilean moons do in much larger telescopes, like the U.S. Naval Observatory’s magnificent Clark refractors. Mars’ low altitude makes it easier to steadily hold binoculars, and using them on a tripod is also easier. Pointing this out could encourage readers to buy/own quality binoculars. **— Daniel Costanzo,** astronomy affiliate for the Washington Academy of Sciences

Corrections

“How small is that star?” on p. 14 of the August 2018 issue incorrectly states the radius of Gliese 229. The star’s correct radius is 0.69 R_{Sun}. The labels for Proxima Centauri and Gliese 229 are also reversed; the larger of the two stars is Gliese 229.

In “Exoplanets burst onto the scene,” also in the August 2018 issue, the caption at the top of p. 55 incorrectly labels the parent star of the TRAPPIST-1 planetary system as Proxima Centauri. The planetary system actually orbits the star TRAPPIST-1.

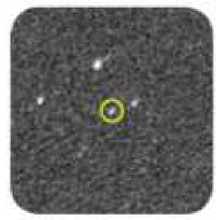
QG QUANTUM GRAVITY

EVERYTHING YOU NEED TO KNOW ABOUT THE UNIVERSE THIS MONTH . . .

HOT BYTES >>

TRENDING TO THE TOP

STRANGE NEW WORLD
A University of Florida-led team identified a potentially habitable super-Earth around 40 Eridani A — the host star of Mr. Spock's home world, Vulcan, on *Star Trek*.



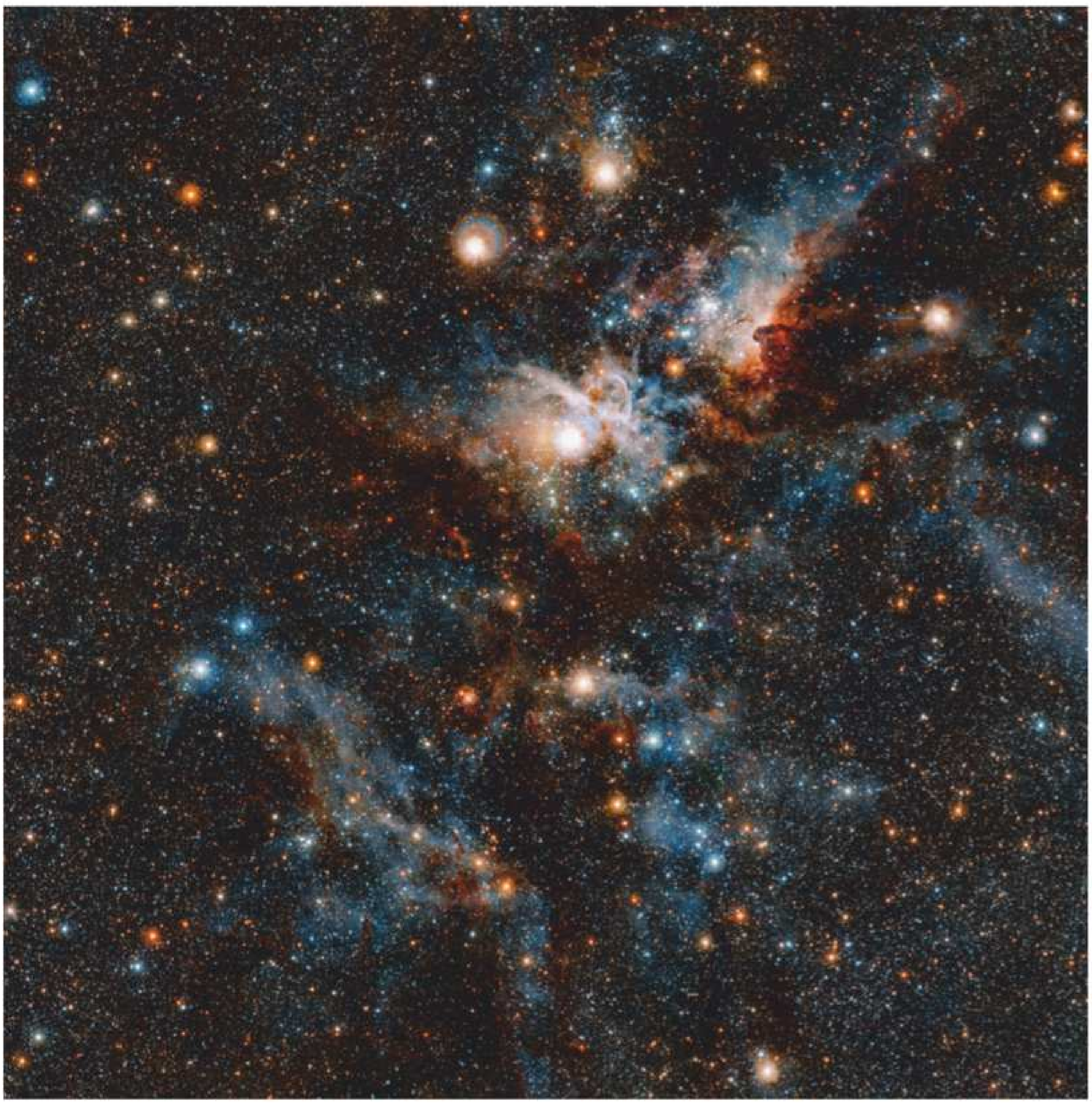
FIRST SIGHT
On August 17, NASA's OSIRIS-REx spacecraft snapped its first image of its destination: the carbon-rich asteroid Bennu.

LOOK DOWN
Conditions on ancient Mars could have allowed life to thrive below the surface for hundreds of millions of years, a Brown University study finds.

SNAPSHOT

The invisible Carina Nebula

Infrared light offers a peek inside a star-forming region.



ESO/J. EMERSON/M. IRWIN/J. LEWIS; TOP FROM LEFT: JPL-CALTECH; NASA/GODDARD/UNIVERSITY OF ARIZONA; NASA/JPL-CALTECH

The Carina Nebula (NGC 3372) is a massive star-forming region within the Milky Way, stretching more than 300 light-years across. In visible light, dust and glowing gas block the view of forming stars hidden within visually striking but dark clouds. But infrared instruments, capable of sensing heat, can penetrate the dust and gas to reveal what's going on inside. Infrared images such as this tableau captured by the Visible and Infrared Survey Telescope for Astronomy, or VISTA, are helping astronomers better study the region.

So far researchers have cataloged almost 5 million individual sources of infrared light within the nebula, identifying forming stars down to just a tenth of the Sun's mass. Other, better-known features of the Carina Nebula include Eta Carinae, an intensely bright binary star system visible above the dark "V" created by cold dust. Another of the region's famous features is the Keyhole Nebula, a dense cloud of gas to the right of Eta Carinae that contains several massive stars.

Over time, young stars destroy the nebulae in which they are born. Their energetic light destroys or blows away the gas and dust surrounding them. But the early stages of star formation are still shrouded in mystery — as well as in dust — making infrared observations that can cut through the dark, obscuring material vital to completing astronomers' picture of how our galaxy and others birth new suns and planetary systems. **— Alison Klesman**

DELAYED DEVELOPMENT. Jupiter's growth into a giant planet was delayed for about 2 million years while it absorbed kilometer-sized rocks, which temporarily stifled the planet's ability to accrete more gas.

TESS RELEASES FIRST ROUND OF EXOPLANET CANDIDATES

The newest planet-hunting spacecraft is off to a promising start.

NASA's Transiting Exoplanet Survey Satellite (TESS) has been scouring the skies for nearby worlds since it began science operations in July. Its first batch of data is now available to astronomers, and already dozens of new exoplanet candidates are awaiting follow-up data to confirm their existence.

During its initial observing campaign, the mission studied 15,900 nearby stars. In 73 cases, TESS witnessed a brief dimming of light suggesting an object, such as a planet, passed in front of the star. But not all dips in starlight are caused by planets; other processes, such as starspots or variability, also can change brightness. And some dips may be caused by companion stars, rather than orbiting planets. TESS principal investigator George Ricker of MIT told *Astronomy* that up to 20 percent of the new candidates will probably be ruled out of planetary status. The remaining candidates, though, are bound to be hot research commodities; some are planets astronomers have already cataloged, but Ricker estimates that six are likely newly found real planets.

FIRST LIGHT. Over the course of 30 minutes on August 7, TESS observed a rich area of the southern sky. This portion of TESS' first-light science image shows the bright star R Doradus (left), as well as a portion of the Large Magellanic Cloud. NASA/MIT/TESS

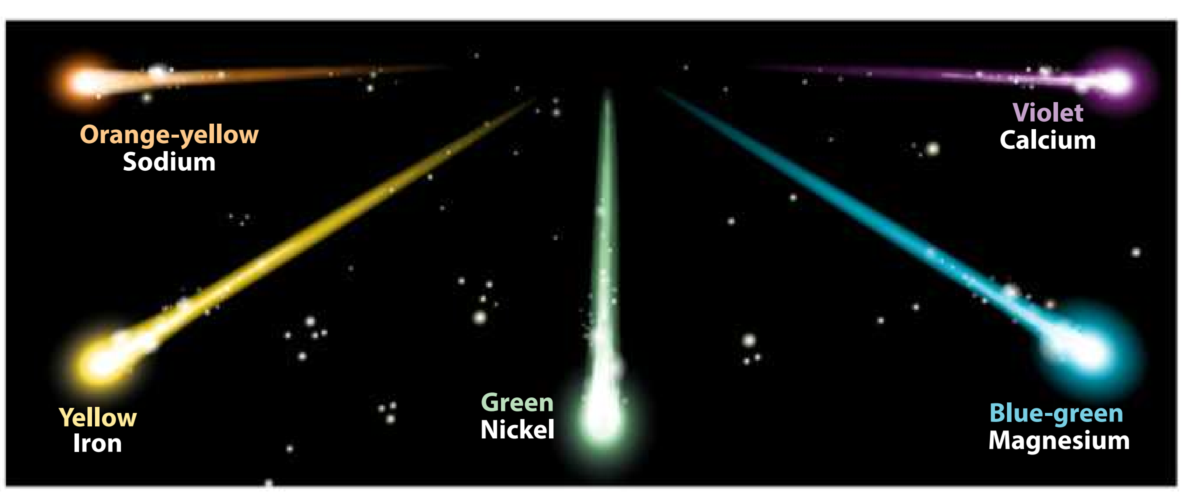
Four eyes on the sky

TESS' workhorses are its four wide-field cameras, each with a 24°-by-24° field of view. The spacecraft breaks the sky up into 26 sectors, staring at each for 27 days. TESS' current mission is set for a length of two years, during which it will cover 85 percent of the sky. The spacecraft sends back data every 13.7 days, when it makes its closest approach to Earth on its unique orbit. Most of the stars it will study lie between 30 and 300 light-years from Earth — closer and brighter than the stars studied by its predecessor, the Kepler space telescope, which means they're also easier to follow up from the ground.

"We make alerts available to astronomers worldwide, and we continue to do that because there are a lot of amateurs with superb instruments they can use for the initial parts of the screening," Ricker said, adding the process will likely take months or years due to the number of planetary candidates to double-check. "As we become more adept at seeking these things out, we are going to get 100 or 200 more [candidates] per sector. There will be a lot to work through. I expect there are going to be 3,000 or so potential objects of interest."

This first round represents only a fraction of the planets TESS hopes to uncover. While large planets are easiest to spot, mission planners also expect TESS to find at least 50 planets no larger than four times the mass of Earth. With TESS already off to an impressive start, this goal doesn't seem too far out of reach. **—Amber Jorgenson, Elizabeth Howell, A.K.**

THE COLOR OF A METEOR



ASTRONOMY: ROEN KELLY

NIGHT LIGHT. When a meteor streaks through the night sky, it will often emit a distinctive glow that can reveal a lot about its composition. But although the chemical makeup of a meteor plays a vital role in producing the color we observe, it's not the only factor; the atmospheric molecules that a meteor barrels through also help determine the overall color of the streak. For example, ionized nitrogen and oxygen can glow with a blue, green-yellow, or reddish hue when energized. **—Jake Parks**

The term *meteor* (a noun) stems from the Greek adjective *metéōros*, meaning "raised from the ground, hanging, lofty," which explains why meteorology has little to do with cosmic objects.

FAST FACT

U.S. ARMY

Cleared for landing

TOUCHDOWN. NASA successfully wrapped up its testing of the Orion spacecraft's parachute system in September. In the last of eight tests, a mock Orion craft was released from a C-17 aircraft and parachuted safely to Earth — officially proving its safety for manned missions. NASA engineers tested the parachute under a variety of situations, from perfect skies to abnormal conditions and possible failure scenarios. Orion can now continue preparing for a three-week, unmanned test scheduled for 2020. If successful, the craft could serve as a home to astronauts a few years later as they travel to the Moon and even Mars. **—A.J.**

ASTRO**NEWS** **UNFAMILIAR FEATURE.** The dwarf planet Ceres' unique mud volcanoes appear to mix volcanism, which involves melted rock, with cryovolcanism, which erupts water, salts, and other molecules.

No red nova in 2022

It's a hard truth: Good science is mostly about meticulously testing informed predictions. And, sadly, these predictions often fall flat.

This is exactly what happened with one of the most anticipated astronomical events of the upcoming decade: the expected merger and visible explosion of a pair of nearby binary stars in 2022.

Five years ago, Calvin College astronomy professor Larry Molnar and his team began analyzing a pair of tightly bound stars — known as KIC 9832227 — located 1,800 light-years away in the constellation Cygnus the Swan. After bolstering their observations with archival data going back as far as 1999, in 2017 Molnar's team made an exciting, first-of-its-kind prediction: that the stars were already tangled up in a complicated dance that would soon end with a merger, called a red nova, in 2022.

But in a study published September 7 in *The Astrophysical Journal Letters*, another team of researchers led by Quentin Socia, a graduate student at San Diego State University, scrutinized Molnar's original prediction. They ultimately concluded the prophesied explosion will not happen as planned. And, just our luck, Molnar himself agrees.

To verify (or in this case, disprove) Molnar's original prediction, Socia and his team concentrated on a gap in observational data — from 1999 to 2007 — for KIC 9832227. After obtaining previously unpublished data captured in 2003, the researchers discovered a curious discrepancy between when the two stars were expected to eclipse each other, and when they actually did. This led Socia's team to dig a little deeper.

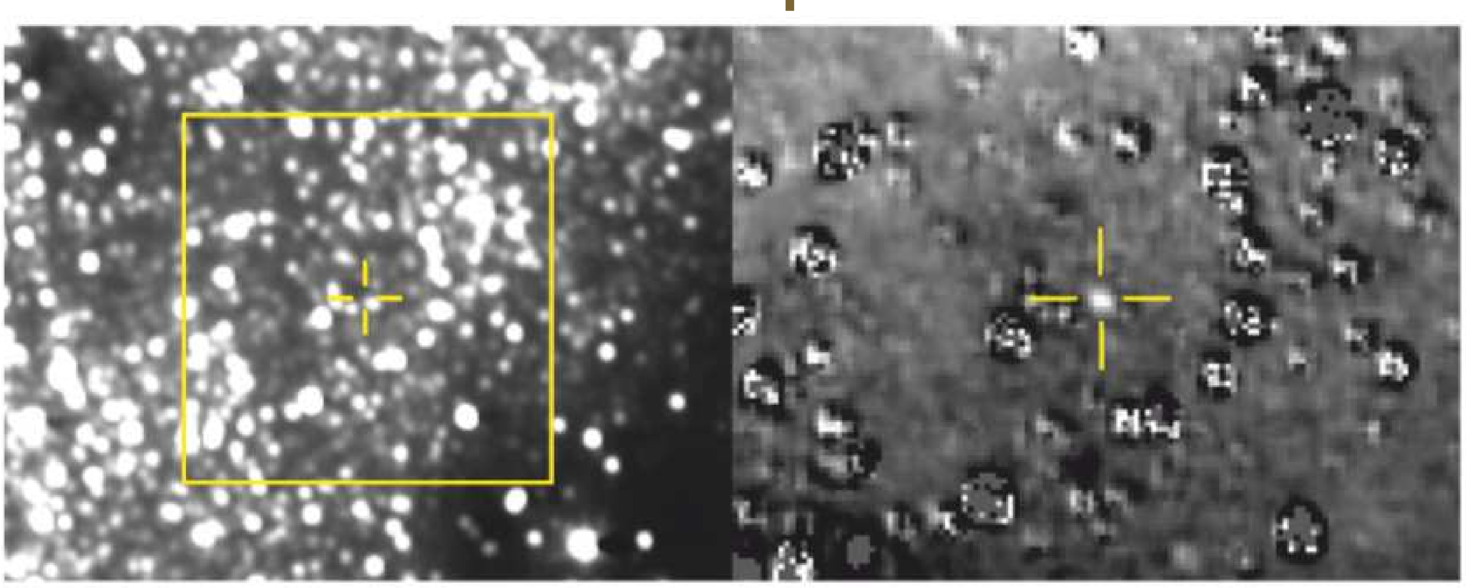
As they fastidiously analyzed a 2004 paper describing the earliest measurements in 1999, the team discovered a simple typo. The 2004 paper's authors had incorrectly transcribed the time of an observed eclipse by precisely 12 hours. This innocent mistake threw off Molnar's calculations for the timing of future eclipses, and therefore his resulting merger prediction.

However, if there is a small ray of light we can pull from this disappointing news, it's the fact that the foundational science that led to Molnar's original prediction is still sound. Researchers hopefully will find — and exhaustively confirm — a new potential merger in the near future. **—J.P.**

NASA/HUBBLE HERITAGE TEAM (AURA/STScI)

RED LIGHT. V838 Monocerotis, imaged here, exploded as a "red nova" in January 2002, suddenly becoming 600,000 times brighter than our Sun. A similar explosion was expected to occur at KIC 9832227 in 2022, but the unprecedented prediction recently fell through.

New Horizons takes its first picture of Ultima Thule



NASA/JHUAPL/SwRI

TARGET ACQUIRED. On August 16, NASA's New Horizons spacecraft snapped its first picture of Ultima Thule, a Kuiper Belt object the spacecraft will approach January 1, 2019. Taken from roughly 107 million miles (172 million kilometers) away, the composite image (left) picks out tiny, dim Ultima (indicated by the yellow crosshairs) from a thick crowd of bright stars. At right is a magnified view of the area within the yellow box, with the stars subtracted to show the distant Kuiper Belt object more clearly. This image, and more to follow, will help the craft stay on course during its journey through the Kuiper Belt. Ultima Thule orbits about a billion miles (1.6 billion km) past Pluto, and if New Horizons' approach is successful, will be the most distant object ever explored. **—A.J.**

QUICK TAKES

TITANIC STORM
Saturn's moon Titan has giant dust storms, making it the third world in the solar system (in addition to Earth and Mars) with a known dust cycle.

ONE-DAY FORECAST
Researchers accurately predicted the large-scale structure of the Sun's corona during the 2017 total solar eclipse, providing a stringent test of solar models.

CRACKING COMETS
By uncovering subsurface deposits of ice, avalanches and landslides may be key to keeping comets active long after surface ice escapes into space.

WATER SPOUT
Scientists identified hydrogen and oxygen in clouds above Jupiter's famous Great Red Spot, backing theories that the planet has abundant water.

A LIGHT SNACK
Strangely moving stars in the Large Magellanic Cloud suggest it consumed a companion galaxy some 3 billion to 5 billion years ago.

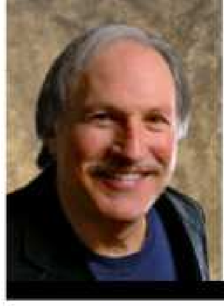
FROM THE MIST
Water-laced dust grains within the material that formed Earth could account for the quick appearance of massive oceans on our planet.

MAKING WAVES
Magnetic waves passing through enormous clouds of gas and dust may be an important factor in forming new stars.

ARE WE THERE YET?
Two brown dwarfs with 70 and 75 times Jupiter's mass are raising questions about where the boundary between brown dwarfs and stars lies.

HEAT SEEKING
Hubble spotted an unusual heat signature around an isolated neutron star, possibly from a disk of material that settled back around the star after it went supernova.

GOTCHA!
A net from a spacecraft successfully caught a tiny CubeSat as part of the European RemoveDebris experiment, which is currently testing methods for capturing space junk. **—J.P.**



STRANGEUNIVERSE

BY BOB BERMAN

Will there be blood?

Totality means something totally different during a lunar eclipse.

The Danjon scale rates the color of the Moon during a lunar eclipse, from nearly black to rust red to copper-orange. *ASTRONOMY*: ROEN KELLY

The most awesome experiences — in or out of astronomy — make silence impossible. Shouts and gasps accompany the precious minutes of totality during a solar eclipse, or a brilliantly animated aurora, or a sudden exploding meteor when it cleaves the night in a shower of sparks.

A lunar eclipse does no such thing to most people. For this reason — to avoid overselling the event — one might use an adjective like "worthy" or "favorable" rather than "mind-blowing." Still, eclipses of the Moon are fascinating enough, and they shouldn't be missed.

The total lunar eclipse on the night of January 20/21 is very favorable. The entire event is visible from virtually all of North, Central, and South America. In most places, the Full Moon is very high up, with the partial phases of the eclipse beginning just after 10:30 P.M. EST and around dinnertime on the West Coast.

As the Moon pushes farther into Earth's shadow at 2,290 mph (3,685 km/h), many describe the Moon's quickly changing appearance as "a series of phases," but it doesn't look at all like the lunar shapes seen each month. These phases are alien. They're seen on no other occasion. The weirdest occur during the half-hour before totality — shadows that slash diagonally across the Moon's face, rather than the curved crescents we expect. If you must choose one viewing window to watch during the eclipse, it should be then.

When the eclipse is total an hour later, the shadow has changed from the inky black at the beginning of the event to a coppery red. It's beautiful. Anyone on the Moon would see the black cameo of a "New Earth" surrounded by a brilliant crimson circle: all our planet's sunrises and sunsets combined into a single red ring.

There's a dramatic difference between totality during a solar eclipse and the same word when applied to the Moon. Solar totality is almost a frantically intense affair, typically lasting two to four minutes. Many phenomena suddenly and briefly appear. Should you gaze at the delicate, lacy magnetic lines of the corona? The hot pink "flames" of prominences? Look for Mercury and Venus in the sky? Use binoculars? Watch the reactions of the stunned people around you? Check out the distant horizons where the Sun is still weirdly shining? Take pictures using exposure bracketing? There's not much time for too many things.

But lunar totality lasts an hour. And nothing is happening. OK, from rural sites, the sky is now dramatically starrier than when it was washed away by the Full Moon an hour earlier. But besides that, what useful observations can you make?

The traditional answer is to determine lunar totality's color and darkness.

When you think about it, there aren't many celestial objects that change color. It's a shame, since we astronomers are chronically tint-deprived. In dim light, only our retinal rod cells operate, and they're colorblind. It's why I consider colorful targets a don't-skip part of every public viewing session. Otherwise it's a firmament of off-whites.

On January 20, the Moon will have real color, deep color.

Sirius' gorgeous saturated prismatic colors do take one's breath away. Or, move your eyes from Sirius' blue to Betelgeuse's red. Of course, if we used a paint store color swatch, we'd have to admit that those stars are actually diamond (blue-white) and pastel yellow-orange — pumpkin diluted with white. But now on January 20, the Moon will have real color, deep color.

Or maybe it won't. In 1921, André-Louis Danjon invented a five-point scale (which runs from 0–4) for judging lunar totalities because he believed the color varies with different parts of the sunspot cycle.

It's still unclear whether he was right. But earthly atmospheric pollutants, such as volcanic dust, definitely affect the Moon's appearance. After Mount Pinatubo erupted in the Philippines on June 15, 1991, the total eclipse of the Moon 18 months later was almost black. Danjon would have rated it a 0. And our skygazing group did just that as we watched from a hilltop outside of Woodstock, New York.

Backyard astronomers used to frequently contribute such appraisals, writing, "I rate this eclipse a Danjon 3," which meant it was brick red with a yellow edge to the shadow. In the 2010s, we had some eclipses that looked like a 4, meaning a bright copper red or orange center with a bluish rim.

Yes, bluish. A Blue Moon? No joke. It's definitely more likely this month than the "Blood Moon" term you'll see in the mass media, since it's between rare and impossible for Earth's shadow to appear dark red like hemoglobin. But hey, maybe it'll happen. And there you have it — the eclipse's exact color and darkness will be a definite, surefire "unknown" that's far from oversold, coming up on January 20.

You have your work cut out for you. Send us your report.

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ASTRO**NEWS** **MILKY WAVES?** The Milky Way experienced a cosmic "fender bender" with the Sagittarius Dwarf Spheroidal Galaxy in the past 300 million to 900 million years, sending stars rippling through our galaxy.

AI detects 72 new fast radio bursts

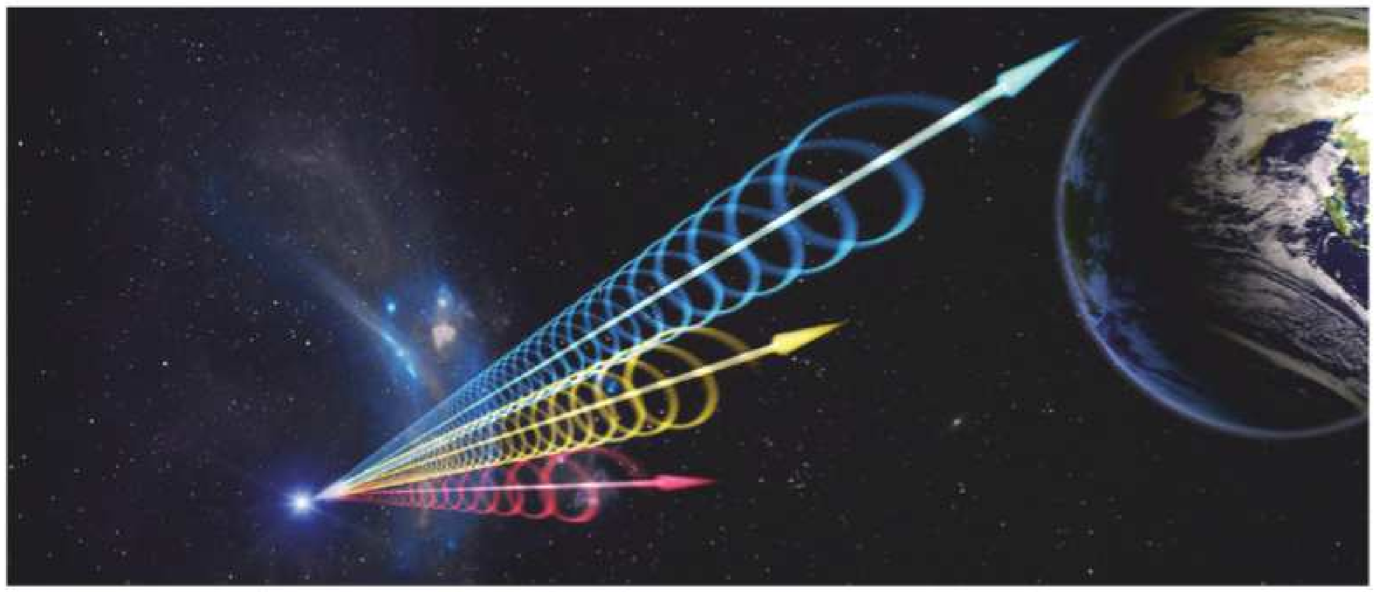
Fast radio bursts (FRBs) are bursts of radio waves, each lasting only a few milliseconds, from far outside the Milky Way. They are among the most puzzling astronomical phenomena. FRBs are difficult to study because most are singular in nature, emitting only one unprompted blast. But one FRB, called FRB 121102, frequently shoots out radio waves from a galaxy 3 billion light-years from Earth.

Now, astronomers have begun using machine-learning technology to spot more bursts than ever before. Their results have been accepted for publication in *The Astrophysical Journal*.

In August 2017, researchers at Breakthrough Listen, which scans the skies for signs of extraterrestrial communications in association with the Search for Extraterrestrial Intelligence (SETI), took an in-depth look at FRB 121102. During an observing session using the Green Bank Telescope in West Virginia, they detected 21 FRBs from the galaxy in one hour. The data indicated that the radio waves switched between periods of extreme and zero activity.

But because the standard computer algorithms used to find the 21 bursts have limitations in their ability to recognize real patterns amid background noise, University of California, Berkeley, Ph.D. student Gerry Zhang created a more powerful machine-learning algorithm to scan the dataset for additional FRBs. That new algorithm revealed 72 new FRBs from the galaxy lurking in the data, the largest number detected in a single observation period.

After analysis, Zhang and his colleagues found no patterns in the arrival times of the 93 total FRBs shorter than 10 milliseconds. This information will help constrain models to better pin down the size and type of object giving off the bursts. With additional observations, Zhang and his team hope to further track signal arrival times and radio frequencies, ultimately pinpointing the source of these mysterious phenomena. **—A.J.**



STRANGE SIGNALS. FRBs send intense pulses of radio energy to Earth for only a few milliseconds at a time. An artificial intelligence algorithm developed by researchers associated with SETI helped scientists identify 72 new outbursts from a distant source. JINGCHUAN YU, BEIJING PLANETARIUM

ASTRONEWS

AND THE AWARD GOES TO . . . NASA's Jet Propulsion Laboratory won an Emmy for outstanding coverage of the Cassini spacecraft's death plunge into Saturn, dubbed the Grand Finale.

ESO

A galactic gem

SOUTHERN BEAUTY. NGC 3981 appears in unprecedented detail in this image captured with the Very Large Telescope from Paranal Observatory in Chile and released September 12. Tilted at a steep incline with respect to Earth, the galaxy's bright disk is swimming with young stars, and its outer spiral arms show evidence of a past encounter with another galaxy. Surrounded by vivid foreground stars, NGC 3981 sits about 65 million light-years from Earth and, like the Milky Way, is a member of the Virgo Supercluster. The European Southern Observatory snapped this photo as part of its Cosmic Gems Programme, a public outreach initiative that images the night sky when conditions aren't ideal for science observations. **— A.J.**

SEE THE CONSTELLATION?

ASTRONOMY: ROEN KELLY

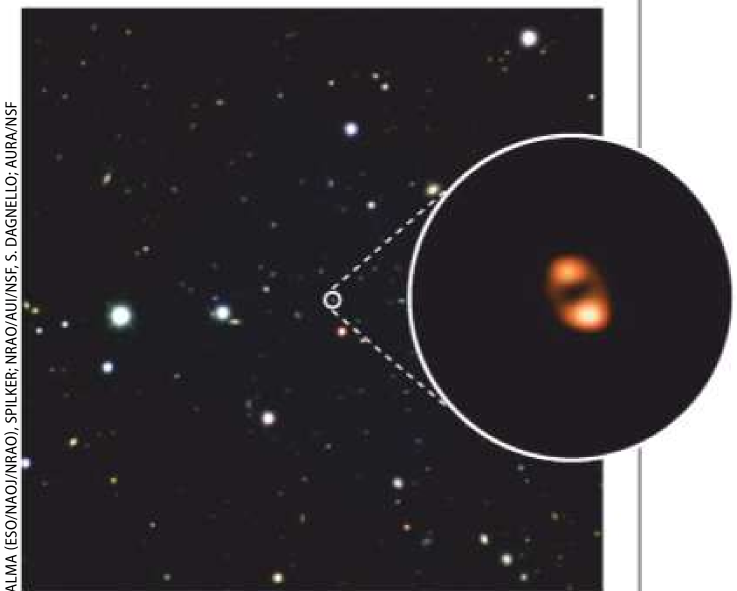
HIDE IN PLAIN SIGHT. As I travel (especially to observe), I often need a quick reference of constellations that are visible from certain latitudes. One of the amazing side notes I've discovered is that some part of 16 of the 88 constellations (18 percent) is visible worldwide at some time during the year. You probably could have guessed many of them, but Canis Minor? Really? You'll find the list to the right. **— Michael E. Bakich**

THE LIST

Aquarius
Aquila
Canis Minor
Cetus
Eridanus
Hydra
Leo
Libra
Monoceros
Ophiuchus
Orion
Pisces
Serpens
Sextans
Taurus
Virgo

FAST FACT

Two constellations — Chamaeleon and Octans — have the most limited visibilities. Both are invisible above 15° north latitude.



ALMA (ESO/NAOJ/NRAO), SPILKER; NRAO/AUI/NSF, S. DAGNELLO; AURA/NSF

BIG BLOWOUT. Researchers used ALMA to spot a young galaxy (circled) blowing molecular gas away from its boundaries, as seen in orange. The blowout appears double lobed because the distant galaxy is gravitationally lensed, which distorts the image.

Powerful winds prevent galactic burnout

Astronomers have long wondered how ancient galaxies bursting with stars avoid "burning out" too quickly. In a paper published September 7 in *Science*, a team of researchers spotted forceful winds of molecular gas gusting away from a galaxy over 12 billion light-years away. The find suggests that by blowing gas away, ancient galaxies had the ability to regulate star formation and keep forming stars over time.

The team used the Atacama Large Millimeter/submillimeter Array (ALMA) to study SPT2319–55, a galaxy churning out stars just 1 billion years after the Big Bang. With the help of gravitational lensing, which occurs when a massive foreground object bends and magnifies light from a more distant source, the researchers were able to see winds of hydroxyl molecules — a prominent ingredient in star formation — shooting outward from the galaxy at nearly 500 miles (800 kilometers) per second.

"So far, we have only observed one galaxy at such a remarkable cosmic distance, but we'd like to know if winds like these are also present in other galaxies to see just how common they are," said lead researcher Justin Spilker of the University of Texas at Austin in a press release. "If they occur in basically every galaxy, we know that molecular winds are both ubiquitous and also a really common way for galaxies to self-regulate their growth." **— A.J.**

1.3 million

The amount (in U.S. dollars) awarded to University of Plymouth researcher Mike McCulloch to develop a spacecraft propulsion method that converts light into thrust.

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FOR**YOUR**CONSIDERATION

BY JEFF HESTER

The Big Bad Bang

Efforts to disprove the theory have produced a century of failure.

It's been almost a century since Alexander Friedman and Georges Lemaître solved Einstein's equations of general relativity for the case of an expanding universe. At the time the idea was something of a theoretician's fever dream, and it seemed unlikely that cosmologists (back when they were just called astronomers) would have much trouble putting the idea in its grave.

Vesto Slipher and Edwin Hubble were the first to take a real shot at it, but they failed. Their observations showed that distant galaxies are moving away faster than nearby galaxies, just as Lemaître predicted. Yes, Hubble's law was really Lemaître's prediction. But when stuff gets named, the one who made the measurements usually gets the glory. Scientists have this funny notion that data matters more than anything.

The score was Expansion 1, Skeptical Cosmologists 0, but it was early in the game. In 1931, Lemaître ran the clock backward and found that an expanding universe must have started out long ago in a hot, dense "cosmic egg." Having a fireball to extinguish brought new opportunities, and in 1948 Ralph Alpher, Hans Bethe, and George Gamow rose to the challenge. They treated the hypothetical fireball as a nuclear physics experiment and calculated what elements it could make. After some fuss, those calculations got the cosmic abundance of helium about right, but left the rest of the periodic table empty. Aha! Maybe there was hope of burying this turkey!

(As an aside, Bethe didn't actually have anything to do with the paper. Jokester Gamow just couldn't resist publishing a paper by "α, β, γ")

On a BBC radio program in 1949, Fred Hoyle first referred to the putative early fireball as "The Big Bang." The name was not meant to heap credibility and honor upon the notion. It's a little ironic that Hoyle played an important role in resolving the kerfuffle over chemical abundances. In 1957, Hoyle, along with Margaret and Geoff Burbidge and Willy Fowler, helped show that stars made the elements that the Big Bang couldn't.

ASTRONOMY: ROEN KELLY

The Big Bang was proving a worthy foe, but cosmologists were just reaching their stride when they hit a brick wall. The single biggest setback in the effort to falsify the Big Bang came in 1964. A couple of guys named Arno Penzias and Robert Wilson were bouncing radio signals off artificial satellites when they discovered that the whole sky glows with microwave radiation.

Penzias and Wilson didn't have a clue what the glow meant, but Robert Dicke and colleagues down the road in Princeton University did. They were preparing to look for just such a fossil from the primordial fireball themselves! Had the sky been found not to be glowing, it would have covered the grave holding the Big Bang's coffin. If life were fair, perhaps Dicke and company would be household names. But again, in science, data rules. In 1978, it was the unwitting discoverers who took a trip to Sweden to pick up their Nobel.

Things were looking bleak in the effort to kill the Big Bang, but while cosmologists were down, they weren't out. The theory predicts that the cosmic fireball's fossil glow must have a blackbody spectrum like that given off by a hot, dense object. Excitement abounded because there were tantalizing hints that the prediction might fail. But when John Mather and George Smoot reported the findings from the Cosmic Background Explorer satellite in 1990, the data were in almost frighteningly good agreement with prediction. I was there that day and can attest to the celebration that followed. But at the same time, it would have been fun if results had turned out otherwise! And yes, Mather and Smoot got their chance to see Sweden.

I've barely scratched the surface of the observational challenges the Big Bang has survived. (I've also played pretty fast and loose with history! Malcolm Longair's *The Cosmic Century* is a good place to turn for that.) The point is that for going on a century, lots of really clever people have devoted themselves to research that, had results turned out otherwise, could have relegated the Big Bang theory to the trash heap. But each time when the smoke cleared, the Big Bang remained.

I groan every time I hear or read someone say that scientists "proved" this or that. Scientific knowledge isn't proven by successful attempts to confirm predictions — ever! Scientific knowledge comes from unsuccessful attempts to falsify predictions. The difference is everything. Friedrich Nietzsche once said, "That which does not kill us makes us stronger." In science, that's pretty much how the game is played.

After the abject failure of cosmologists to lay the Big Bang theory to rest, we know that our expanding universe emerged from a dense fireball 13.8 billion years ago. But don't imagine for an instant that will keep future generations of cosmologists from kicking the tires.

Jeff Hester is a keynote speaker, coach, and astrophysicist. Follow his thoughts at **jeff-hester.com.**

BROWSE THE "FOR YOUR CONSIDERATION" ARCHIVE AT **www.Astronomy.com/Hester.**

MO' MONEY. Japan's science ministry is seeking a 21 percent budget increase (to $10.54 billion) for 2019 to build a new X-ray space telescope and a particle detector.

BINARY SYSTEMS: PART 1

SEEING DOUBLE. Our Sun is a loner, but the galaxy is rife with multiple-star systems in which two, three, or even more stars circle each other. Binary interactions play an important role in the lives of stars that swing around each other; these interactions also influence the light astronomers receive when studying these systems in the sky. (Check out Binary Systems: Part 2 next issue!) **— A.K.**

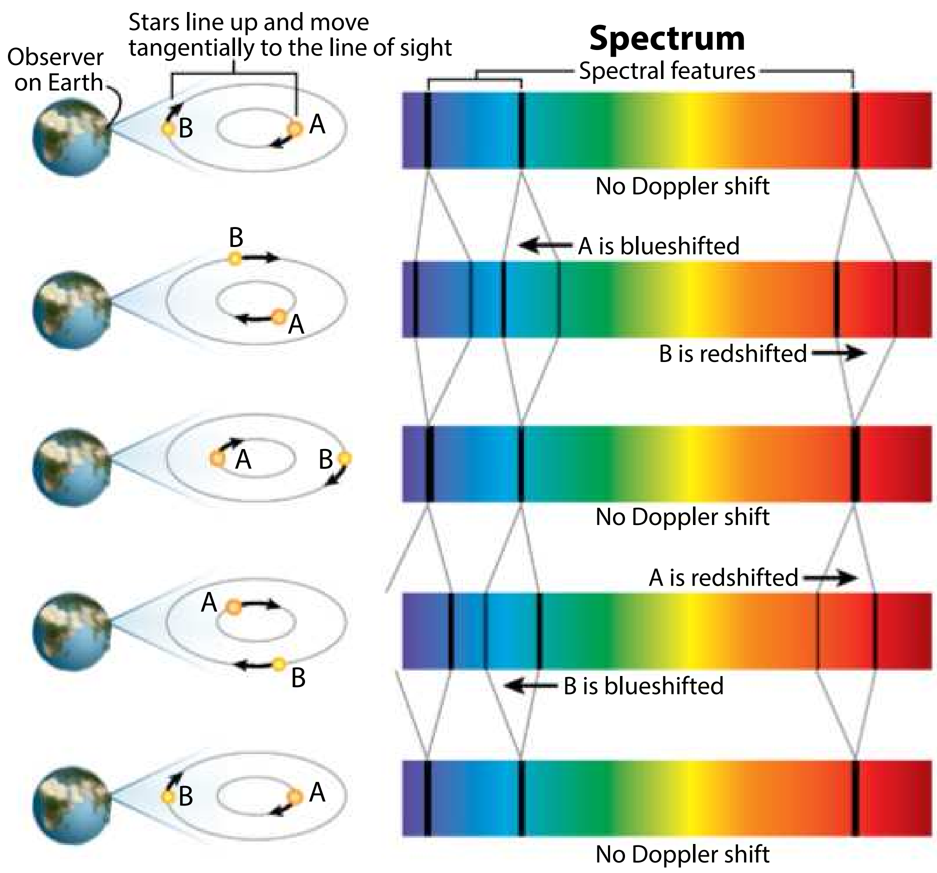
FAST FACT

Algol (Beta [β] Persei) is an eclipsing binary with a period of 2.867 days. Over that time, it dims noticeably — from magnitude 2.1 to 3.4 — before brightening again.

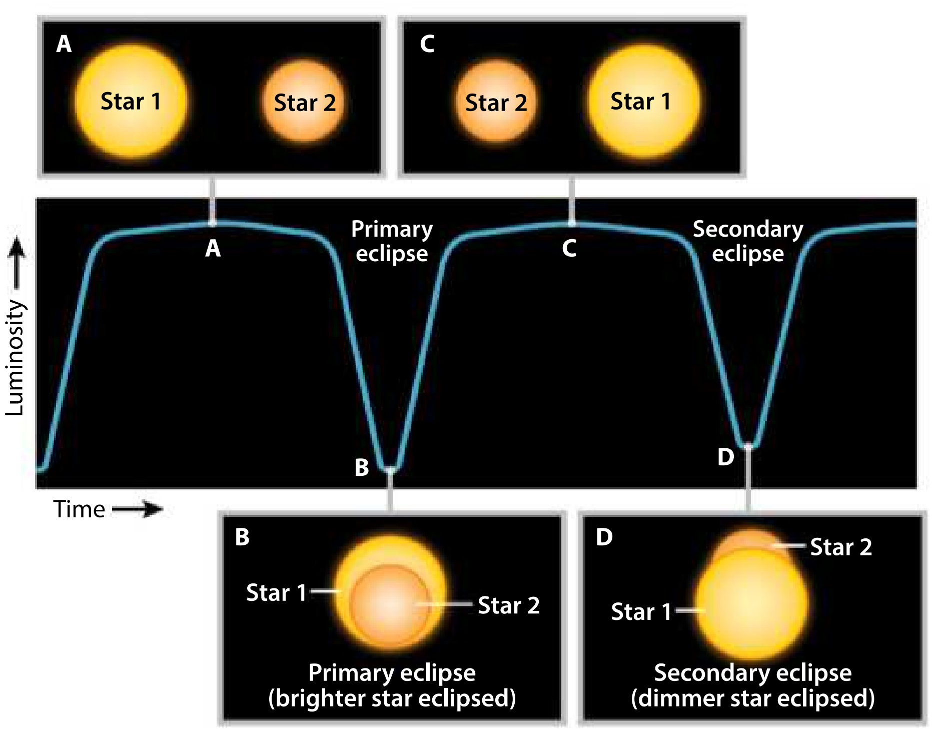
VISUAL BINARIES are the simplest to observe. These can be resolved into separate stars, either by eye or by using a telescope. Not all stars that appear close to each other on the sky are physically associated in a binary system — the only way to determine if stars are truly orbiting each other is to measure the distance or motion of both.

UNIVERSITY OF SOUTH CAROLINA DEPARTMENT OF PHYSICS AND ASTRONOMY

SPECTROSCOPIC BINARIES are discovered by analyzing the light from a star spread out into a spectrum using a prism or grating. These binary systems appear as one star even with the resolving power of a telescope. But when viewed over time, a binary's spectrum will "split" into two sets of features — indicating that two stars are contributing to the light instead of just one — and each will Doppler shift toward the red or blue end of the spectrum as the stars move in their orbits around each other.



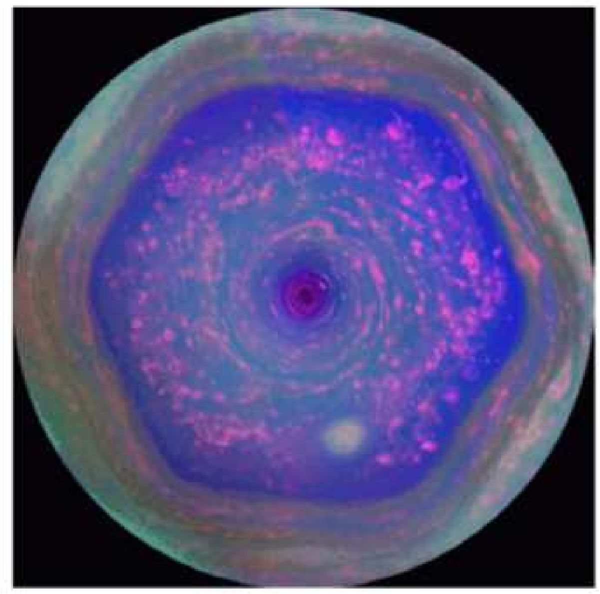
ASTRONOMY: ROEN KELLY



ECLIPSING BINARIES are binary stars in which the entire system is aligned edge-on with our line of sight. When viewed from Earth, one star will periodically pass in front of (primary eclipse) or behind (secondary eclipse) the other, affecting the brightness of the light we receive. Algol is a famous example of an eclipsing binary, in which the magnitude of the system cycles noticeably every 2.867 days, the period of the binary orbit.

ASTRONOMY: ROEN KELLY

100 trillion times The difference in density between neutron star matter and the densest material on Earth.



STUNNING HEIGHTS. Saturn's hexagon is a well-defined, six-sided jet stream swirling at the planet's north pole. This false-color view of the hexagon, captured by the Cassini spacecraft, encompasses latitudes from the planet's pole to 70° north. It is the first color view of the polar hexagon ever captured.

NASA/JPL-CALTECH/SSI/HAMPTON UNIVERSITY

Saturn's hexagon could be an enormous tower

Above Saturn's north pole, low-altitude clouds swirl in a stunning hexagonal shape. Discovered by NASA's Voyager mission in 1981, Saturn's hexagon is striking to behold. Now, a new study published September 3 in *Nature Communications* suggests that the six-sided vortex may actually be hundreds of miles tall.

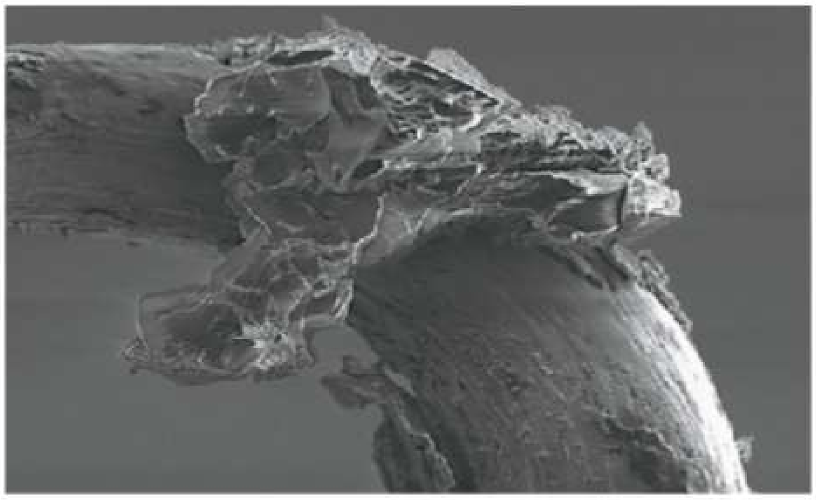
Using Cassini data taken in 2012, a team of researchers led by Leigh Fletcher of the University of Leicester has discovered a high-altitude vortex forming at Saturn's north pole. The vortex was spotted as the northern hemisphere approached summertime, and it has a six-sided shape just like the famous hexagon closer to the planet's surface. These findings suggest that the high-altitude vortex may be an extension of the low-altitude vortex, potentially forming an immense, tall tower.

The discovery of a hexagonal vortex at a higher altitude was a shock to the team. "While we did expect to see a vortex of some kind at Saturn's north pole as it grew warmer, its shape is really surprising," said Fletcher in a press release. "Either a hexagon has spawned spontaneously and identically at two different altitudes, one lower in the clouds and one high in the stratosphere, or the hexagon is, in fact, a towering structure spanning a vertical range of several hundred kilometers."

When Cassini first arrived, temperatures in Saturn's upper atmosphere at the north pole were too cold for its instruments to reliably probe. Only later was it able to detect the high-altitude vortex in the north. The question researchers now want to answer is whether the vortex is actually new, forming seasonally as the atmosphere warms, or whether it is long-lived, like the lower-altitude hexagon. For now, it remains difficult to tell. **— Chelsea Gohd, A.K.**

INDIA AIR. India has announced plans to send astronauts into space by 2022. The goal has been met with skepticism from some critics.

Dust grains reveal asteroid Itokawa's age



ZOOMED IN. A close-up view of a microscopic dust grain from asteroid Itokawa, which was collected by Japan's Hayabusa spacecraft, the world's first mission to return samples from the surface of an asteroid to Earth for further study. Grains like this allowed astronomers to calculate Itokawa's age. ESA

On June 13, 2010, Japan's asteroid-visiting Hayabusa spacecraft earned its name ("peregrine falcon") by dive-bombing through Earth's atmosphere at 7.5 miles (12.2 kilometers) per second. As expected, the spacecraft disintegrated upon re-entry; however, a heat-shielded sample-return capsule survived the fall relatively unscathed, returning a plethora of precious dust grains collected from the loosely bound asteroid known as Itokawa.

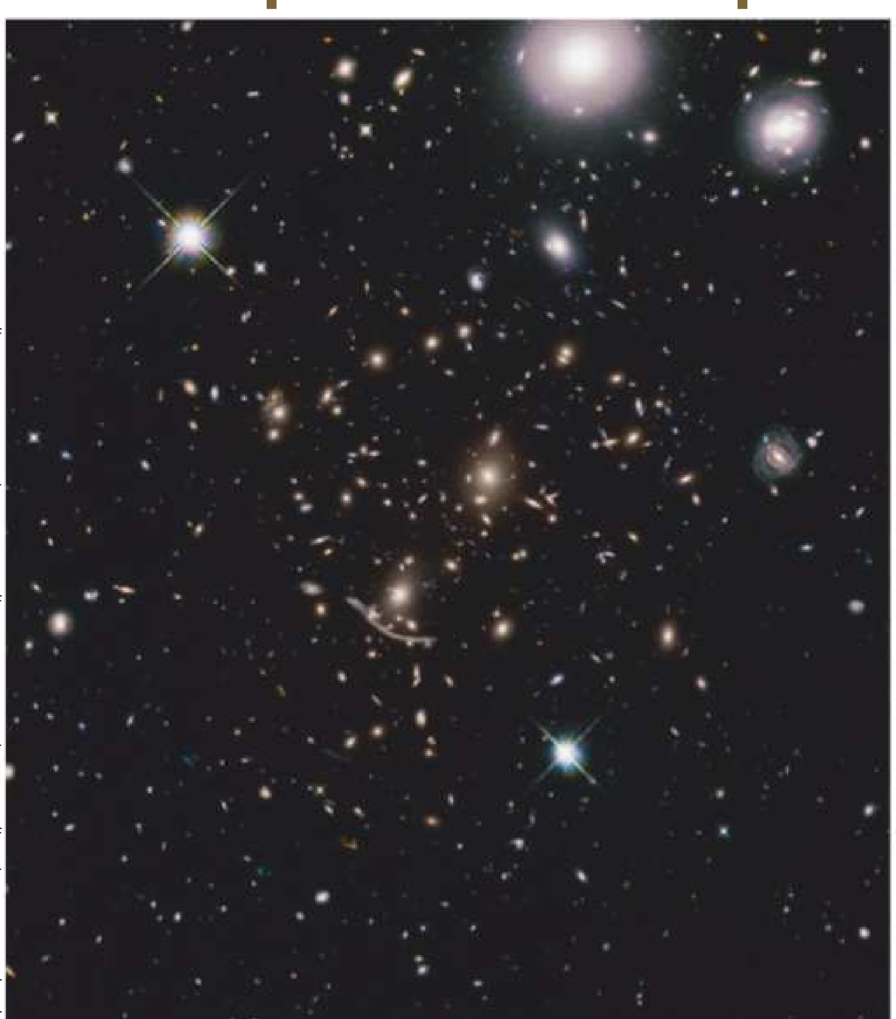
After nearly a decade of closely examining the samples returned by Hayabusa, a study published August 7 in *Scientific Reports* claims to have finally pinned down the origins of the mysterious near-Earth asteroid. Based on analysis of more than a thousand specks of dust from Itokawa, scientists have learned that the primeval pile of rubble formed some 4.6 billion years ago, right around the time the solar system was born.

However, unlike some asteroids, Itokawa apparently has had an eventful life since then. According to the study, about 1.5 billion years ago, a run-in with another asteroid nearly obliterated Itokawa before the remains eventually re-accreted into its present-day form.

Furthermore, the researchers say Itokawa spent most of its life (and death and rebirth) in the asteroid belt, and it was kicked out into its current near-Earth orbit only in the past couple hundred thousand years. And since asteroids don't typically fare well outside the main belt, the researchers predict Itokawa will either break apart or collide with Earth within the next million years.

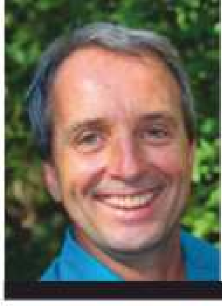
As Hayabusa showed, asteroid return missions can result in fascinating discoveries. With Hayabusa2 and OSIRIS-REx now underway, researchers should soon have a wealth of material to analyze, helping them methodically piece together the complicated history of these cosmic bocce balls. **—J.P.**

Hubble peers into the past



NASA, ESA, A. KOEKEMOER (STSCI), M. JAUZAC (DURHAM UNIVERSITY), C. STEINHARDT (NIELS BOHR INSTITUTE), AND THE BUFFALO TEAM

COSMIC LENS. This stunning image of galaxy cluster Abell 370 kicks off Hubble Space Telescope's new mission — Beyond Ultra-deep Frontier Fields And Legacy Observations, or BUFFALO — to study our universe's oldest galaxies. Abell 370, which is roughly 5 billion light-years away, acts as a second "telescope" to magnify extremely distant, young galaxies through gravitational lensing. Light from galaxies otherwise too far and faint to be seen is magnified and bent by the cluster's massive bulk, allowing astronomers to glimpse the universe's distant past. Hubble will use this handy trick to peer through five additional galaxy clusters and observe galaxies from a time when the universe was less than 800 million years old. By witnessing the actions of these first galaxies, researchers will gain invaluable knowledge about their formation and evolution into the galaxies we see today. **—A.J.**



SECRET**SKY**

BY STEPHEN JAMES O'MEARA

Wonders of lunar totality

How an eclipse of the Moon can play tricks on your eyes.

The total lunar eclipse on July 27/28 was superlative in many ways. It occurred at lunar apogee, when the Moon is farthest from Earth and appears smallest. It also occurred near aphelion, when Earth is farthest from the Sun. These two circumstances resulted in totality lasting 103 minutes, the longest of the 21st century. The next similarly long eclipse won't occur until 2029.

Finally, the fully eclipsed Moon — sometimes called a Blood Moon, owing to its reddish color — was near Mars (the Blood Planet), which was closest to the Sun for its current orbit. And that took place just prior to Mars' closest approach to Earth, when it appears brightest in the sky. Thus, this "micro Blood Moon near macro Blood Planet" made for some pronounced optical effects that added to the drama of this remarkable event.

A view from the south

I watched the entire eclipse under a clear sky from Botswana. Totality occurred nearly overhead in Capricornus but close to the Sagittarius border, with all that gorgeous Milky Way. It was a classic eclipse in every way. As hoped, the stratosphere continued its longest clear stretch since the 19th century, and the central eclipse performed as expected, appearing coppery red at mid-totality.

On the Danjon scale, a five-point scale (from 0 to 4) that measures the appearance of totality, this translates to a value of 2, with some surface details visible to the unaided eye. The beginning and end of totality had brighter Danjon values of 2.5 and 3, respectively, with the post-totality phases appearing more colorful than the pre-totality phases.

Visual oddities

Warped shadow: One dramatic effect of the partial phases was the appearance of intense irregularities along the limb of Earth's shadow when viewed with the unaided eye. This optical illusion usually manifests whenever Earth's curved shadow mingles with dark lunar mare, kicking the eye-brain combo's pattern-recognition "software" into high gear. The result is that we see dark protrusions jutting from the shadow.

These protrusions were most apparent near the beginning and end of the partial phases. The Moon's small angular diameter most likely helped to enhance the blending effect, as resolution was at a minimum. Curiously, as the shadow approached Mare Crisium prior to the start of totality, the protrusion I expected to see was hardly noticeable. Instead, angular horns of dim light extending along the Moon's northern and southern limbs lent the shadow a boxy appearance.

Acorn effect: Another prominent phenomenon during the partial phases — something that cannot be captured well in images — occurred when the Moon was roughly half-eclipsed. The bright part outside the shadow formed a large and dazzling cap of light (making the Moon resemble an acorn), while the eclipsed portion was a much slimmer and dimmer chocolate-orange glow. This optical effect, called irradiation, makes bright objects seen against a dark background appear larger than dark objects against a similar (or brighter) background.

Because the total phase of a lunar eclipse usually lasts an hour or more, some people take only an occasional glance at it. But, as the author points out, you'll see many other effects than a simple darkening if you watch the entire event. ALL IMAGES: STEPHEN JAMES O'MEARA

Recent studies have shown that neurons that respond to bright objects may distort those objects more than neurons that respond to dark objects. Our ancestors may have evolved this as an advantage to see in low-light conditions, such as nighttime on the African savanna. Again, the Moon's small apparent size magnified this effect due to increased contrast between the dark and the light.

Shrinking Moon:. Perhaps the most fantastic effect was the apparent diminishing size of the Moon during totality. Those watching the eclipse with me all agreed that the Moon appeared larger at the beginning of the eclipse and became smaller as totality approached. But I expected that, given the Moon illusion.

During totality, the Moon dimmed by at least a full magnitude, appearing fainter than both Mars and Jupiter but brighter than Saturn. What I did not expect to see was an apparent shrinking of the Moon's angular extent. This optical illusion, which was noticed by everyone without any prodding, must have been an instance of irradiation coupled with the diminutive apparent size of the Moon at apogee — a visual collusion of sorts that served to baffle the brain.

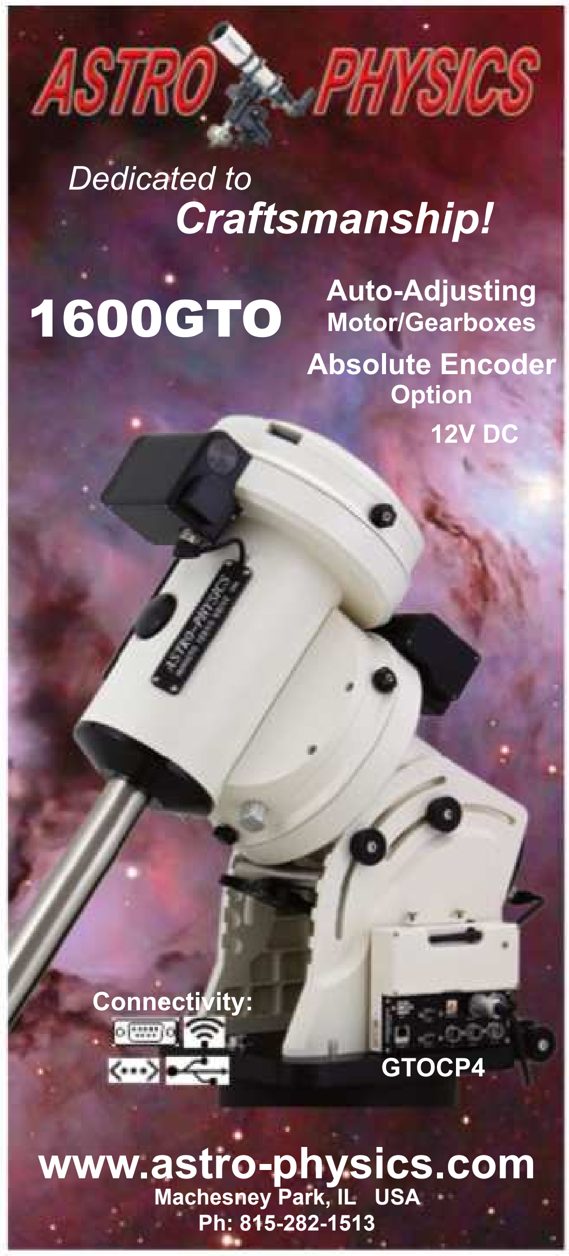
Being aware of your surroundings can yield exceptional lineups, like this one the author captured of Earth, an owl, and the totally eclipsed Moon.

The way to watch

Despite these optical effects that can trick the unaided eye, no view beats the full awe and beauty of a total lunar eclipse through binoculars. And no camera has yet captured the subtleties of light and color playing across the Moon's face that the eye alone can perceive. As always, send your observations and thoughts to sjomeara31@gmail.com.

Stephen James O'Meara is a globe-trotting observer who is always looking for the next great celestial event.

BROWSE THE "SECRET SKY" ARCHIVE AT **www.Astronomy.com/OMeara.**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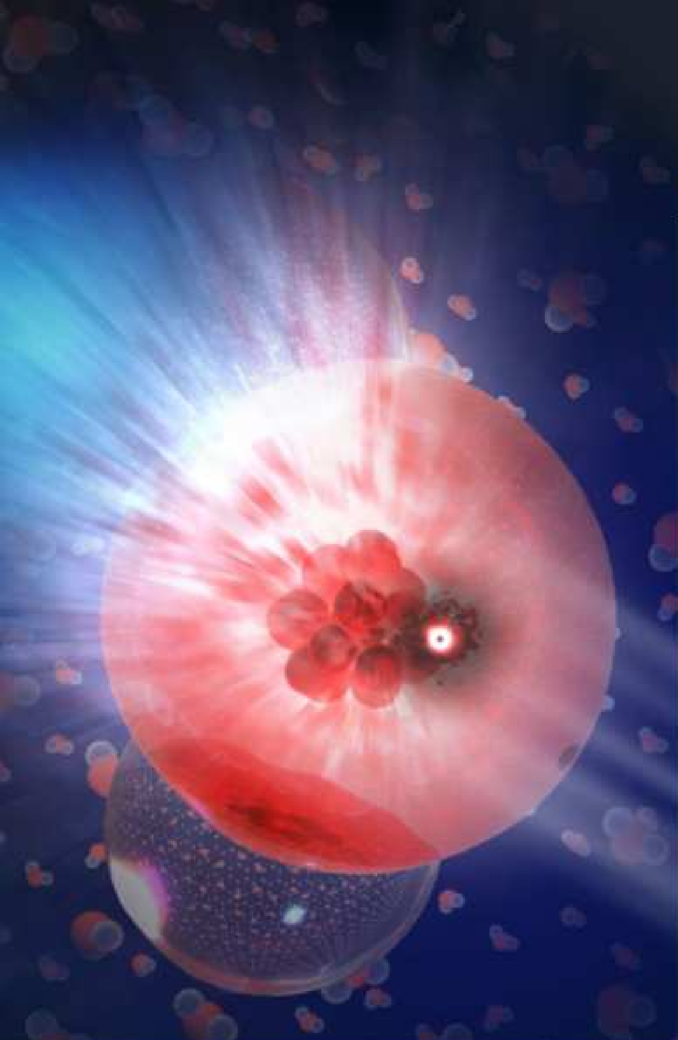
TOP 10 SPACE STORIES of 2018

Last year, a comet from another solar system visited our own, a star swung around our galaxy's supermassive black hole, and a ghostly neutrino revealed its extragalactic source.

by Liz Kruesi



THE UNIVERSE DELIVERED MANY SURPRISES IN 2018, and *Astronomy* always enjoys ranking the top 10 of those cosmic curveballs. The past year spanned everything from the planet next door to the first stars to form after the Big Bang. Taking the top spot is a collaborative discovery that came from a single track of light through Antarctic ice. The neutrino that spawned it, along with others found in old data, shined a new light on the dark depths of an active galaxy's supermassive black hole.

Also on our list is an interstellar interloper — a cometlike object from another planetary system, seen looping around our Sun. Even closer to home is a big announcement in the search for water on Mars: A liquid water lake may exist under the Red Planet's surface.

Here's how these and the rest of the top 10 space stories stack up.

The gas giant Kepler-1625b, depicted in this artist's concept, may have a Neptune-sized moon, based on data from Kepler and Hubble. The pair is calculated to have a mass-to-radius ratio similar to Earth and its Moon, but scaled up by a factor of 11. DAN DURDA

10 STRONGEST EVIDENCE YET OF AN EXOMOON

SCIENTISTS HAVE IDENTIFIED THOUSANDS OF EXOPLANETS ORBITING OTHER STARS. But spying moons orbiting those planets has been a struggle. On October 1, 2018, researchers announced they may have just found the first of these so-called exomoons.

The Kepler space telescope looked for tiny dips in a star's brightness, which can signal a planet passing in front of the star. Columbia University astronomer David Kipping and graduate student Alex Teachey looked at dips from 284 stars. In the signal from one, Kepler-1625, they saw an intriguing second, smaller dip — possibly an exomoon.

Over 40 hours in October 2017, the Hubble Space Telescope (HST) collected light from Kepler-1625. Teachey and Kipping carefully combined the data with the Kepler observations, taking into account differences between the instruments and other sources of uncertainty. "We've tried our best to rule out other possibilities such as spacecraft anomalies, other planets in the system, or stellar activity, but we're unable to find any other single hypothesis [that] can explain all of the data we have" aside from an exomoon, said Kipping in a press conference.

Not everyone is convinced just yet, and Kipping and Teachey acknowledge that more observations are needed. They hope to use HST again in May 2019. The researchers also hope more scientists will probe the results. "Some people will be convinced, and other people will be skeptical," says Teachey, "and that's all part of the process." Indeed, it's the scientific method at work.

9 THE NEXT RUNNER IN THE EXOPLANET RACE

TESS, illustrated here, is NASA's newest planet-hunting spacecraft. Its four wide-field cameras are designed to survey most of the sky, moving to a new patch every 27 days. TESS hunts for planets orbiting nearby stars that can be followed up on easily using telescopes on the ground. NASA'S GODDARD SPACE FLIGHT CENTER

EXOPLANET SCIENTISTS EXPERIENCED A HANDOFF IN THE RACE TO FIND HABITABLE PLANETS ON APRIL 18, when NASA's new exoplanet hunter, the Transiting Exoplanet Survey Satellite (TESS), launched. Three months later, TESS began science operations as the previous exoplanet-search workhorse, the Kepler space telescope, went into safe mode due to low fuel. And on October 30, NASA officially ended the nearly 10-year-long mission, retiring the telescope.

From planets around binary stars to systems hosting multiple small worlds, Kepler's discoveries are the foundation upon which every exoplanet search in the future will be built. And TESS is the first to follow.

Both telescopes use the same detection method: watching for periodic dips in starlight, which indicate an orbiting planet passing in front of its host star and blocking its light. But the types of stars they watch are very different. "Kepler was a pencil-beam survey during the main mission," says University of California, Berkeley, astronomer Courtney Dressing. Initially, Kepler watched the same 100° star field for several years and detected worlds with many different orbital periods — the longest taking more than three and a half years to orbit their stars.

But most of the stars Kepler studied are far away, and therefore dim. Faint light means it's hard to see the details that allow astronomers to measure characteristics such as a planet's mass. TESS' catalog of brighter stars will be easier to follow up on from the ground.

TESS will find worlds orbiting red dwarf stars in our nearby neighborhood, astronomically speaking. It will also scour almost the entire sky in its initial two-year mission, spending 27 days on each portion. "To be sure that we've found a real planet, we like to see it transit many times," adds Dressing. "That means that many of TESS' planets will be very close to the star and go around once or twice a week." Astronomers expect the spacecraft will find thousands of planets orbiting other stars, and perhaps several dozen of those with environments suitable for life.

Kepler revolutionized our understanding of exoplanet systems; TESS should reveal the details of those worlds that lie closer to us and therefore can be studied more exhaustively with readily available ground-based telescopes.

8 EINSTEIN AND THE GALACTIC CENTER

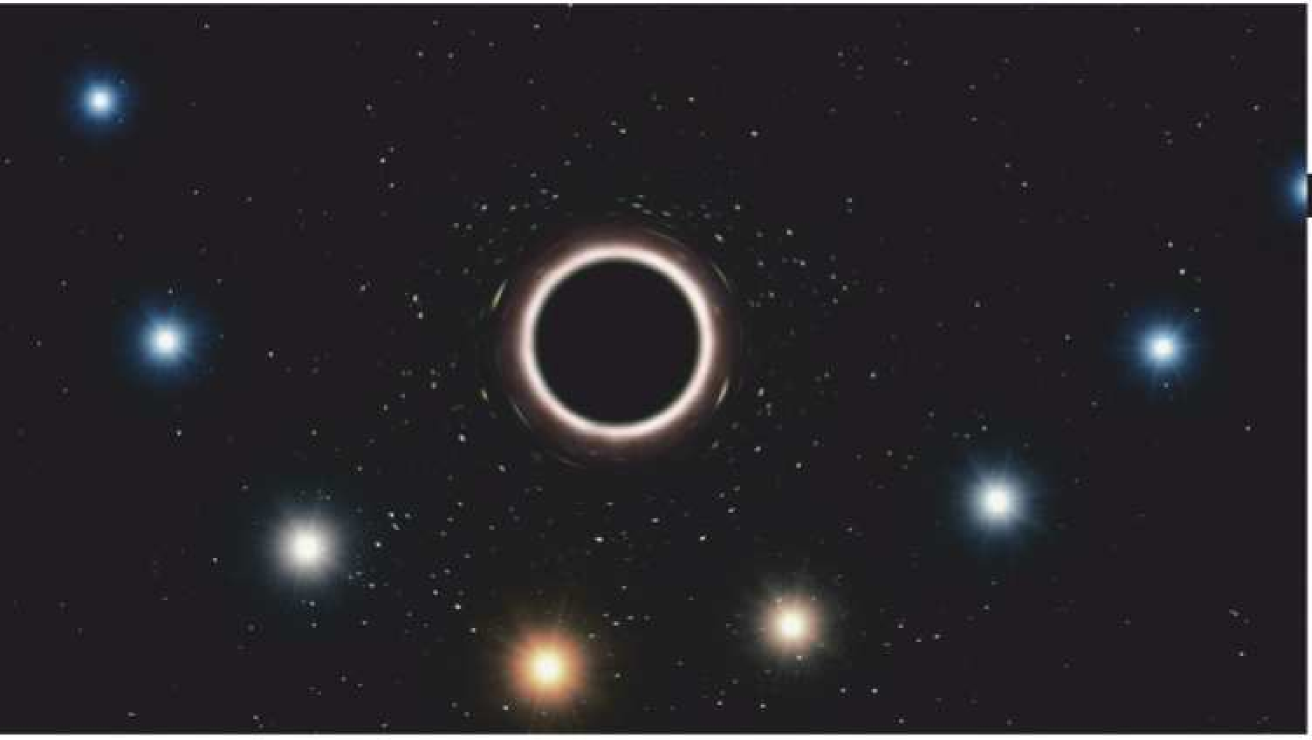
SCIENTIFIC THEORIES LAST FOR AS LONG AS EVIDENCE SUPPORTS THEM. And it looks like Albert Einstein's theory of relativity is here to stay. This past year, another piece of evidence bolstered Einstein's work when astronomers precisely tracked the orbit of a star that happens to swing extremely close to Sagittarius A* (Sgr A*), our galaxy's central supermassive black hole. During that flyby, the star's light acted exactly as Einstein's theory predicted it would in the presence of an immense gravitational pull, stretching out to a redder color.

The international team used a technique called interferometry that allows the four separate telescopes that make up the Very Large Telescope (VLT) in Chile to act as one. Light from each telescope is combined using sophisticated data processing to act as one large detector. That gave the researchers a telescope with an effective diameter of almost 400 feet (120 meters) — a size not possible with a single scope. The instrument used to combine and process the light from the four VLT telescopes is called GRAVITY; it is designed to study Sgr A*

7 A GALAXY WITH ONLY A LITTLE DARK MATTER

YOU'LL LEARN IN ANY INTRODUCTORY ASTRONOMY CLASS THAT A GALAXY IS MADE UP OF STARS, GAS, DUST, AND A WHOLE LOT OF DARK MATTER — an invisible material that acts as scaffolding to the structure in the universe. But in a March 28 *Nature* paper, astronomers announced they'd discovered an outlier: a galaxy that seems to have 400 times less dark matter than predicted.

Yale University's Pieter van Dokkum and University of Toronto's Roberto Abraham developed the Dragonfly Telephoto Array five years ago to look for faint-yet-large galaxies in wide swaths of sky. In a higher-resolution follow-up image of one of these galaxies, which goes by the name NGC 1052-DF2, the galaxy's structure seemed odd — low overall brightness, but several bright clumps of old stars. The researchers used the Keck Telescope in Hawaii



The star S2 recently swung around the Milky Way's supermassive black hole, Sagittarius A*. This artist's impression, which exaggerates both the size and color of the star, shows S2 at various points in its orbit. General relativity predicted that, as it approached the black hole, the star's light would grow redder thanks to the gravitational pull of the massive object. This is exactly what astronomers watching the event saw. ESO/M. KORNMESSER

— an object with a strong gravitational pull.

The team tracked a star known as S2 during its closest approach to Sgr A*. In the same way that Halley's Comet travels an elliptical orbit and swings close to the Sun every 76 years, S2 swings by Sgr A* every 16 years. That closest approach happened May 19, and GRAVITY tracked the star's position to extreme detail over the past year. But it wasn't the only instrument the researchers used to observe S2. While GRAVITY tracked the star's location on the sky, the VLT's Spectrograph for INtegral Field Observations in the Near Infrared (SINFONI) instrument unraveled the star's rainbowlike spectrum of light, revealing the star's motion along our line of sight. As the star swung around the black hole, SINFONI recorded a shift in the color of the star's light associated with its changing orbital velocity. But as S2 neared Sgr A*, the black hole's gravity tugged on its light, creating another shift in the detected light. Sgr A*'s gravity sapped the light of energy, stretching it out to longer wavelengths. The change in color it caused was just 5 percent of the change due to the star's orbital motion, but the researchers were able to pick out that small shift — confirming yet another prediction of Einstein's theory of general relativity.

This work is just the beginning, says team member Jason Dexter. The astronomers are still tracking S2, and they expect to see another effect of general relativity within a year or two. "We will be able to see [that] it is now moving along a different ellipse than before," says Dexter. This effect is called precession.

And even more discoveries might await. GRAVITY provides a factor of 15 better resolution and position accuracy than previous instruments, says team member Stefan Gillessen of the Max Planck Institute for Extraterrestrial Physics. That's nearly the difference Galileo experienced when he first switched from unaided observations to looking through a telescope, four centuries ago. Suddenly, the view became much clearer. "You open up discoveries with such a machine," he adds.

NGC 1052-DF2 is a "see-through" galaxy that appears to have little dark matter, based on the movements of its bright globular clusters over time. Astronomers still aren't sure why this galaxy is so devoid of the strange substance. GEMINI OBSERVATORY/NSF/AURA/KECK/JEN MILLER

to capture a detailed spectrum and measure the motions of several of those clumps of stars. "It turned out they basically appeared to stand still," says van Dokkum. "They should be moving a lot faster than they do. It's uncomfortable because we've never seen anything like that before."

What's making the astronomers uncomfortable? Theory predicts that normal matter — the stuff that makes up stars, dust, and gas — couples with dark matter, meaning the two move together. But the stars in the outskirts of NGC 1052-DF2 are moving three times slower than they would in a galaxy containing the normal amount of dark matter. Based on the clusters' motions, the team also calculated the galaxy's mass. Unlike most galaxies, the majority of NGC 1052-DF2's mass is tied up in normal matter, which can be seen. There's very little unaccounted-for mass — dark matter — and that is very unusual. "It flies in the face of the idea that the dark matter and luminous matter are always coupled," says van Dokkum.

But not all researchers are convinced the Dragonfly team factored in all sources of uncertainty in their analysis. About a dozen scientific papers have followed from other groups, many addressing such uncertainties, though van Dokkum isn't too concerned by the claims from others — he says scientists should question claims and work to confirm or disprove observations that don't seem to fit. "It's all our jobs to do this kind of scrutiny," he says. Only a strong theory or strong claim can withstand trial after trial. And for further analysis, the researchers need more data.

In the fall of 2018, the researchers again used Keck with a new instrument to take more detailed spectra — this time not of the stars in the galaxy's clusters, but of the faint stars that lie between the clusters. "It's a difficult measurement, but we think we can do it," says van Dokkum.

What if the galaxy really does hold such little dark matter compared with normal matter, when every other galaxy shows a much higher percentage? The answer might tell astronomers about dark matter's identity, which remains a mystery.

6 A SIGN OF THE FIRST STARS?

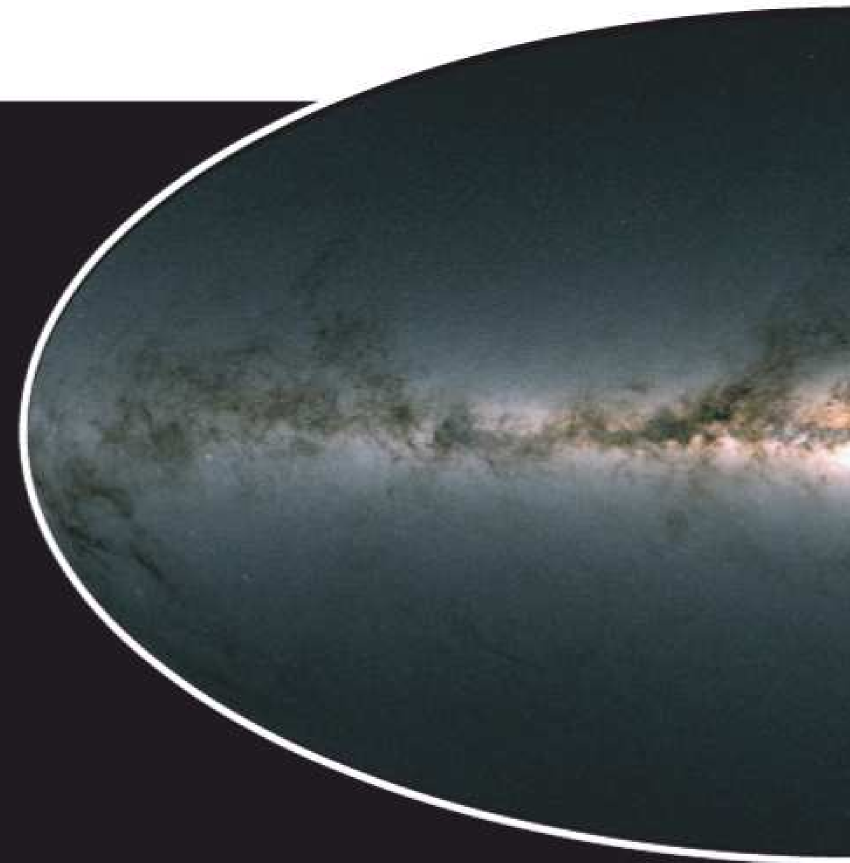
Astronomers envision the first stars as massive, hot objects that lit up the neutral hydrogen gas surrounding them. In this artist's rendering, the cooler cosmic microwave background radiation left over from the Big Bang glows reddish-orange. N.R. FULLER, NATIONAL SCIENCE FOUNDATION

BEFORE THE FIRST STARS LIT UP, THE UNIVERSE WAS VEILED IN DARKNESS. That era is known as the cosmic Dark Ages, not just because of the literal lack of light, but also because it's a chapter of cosmic history that — without light — we have no way to access. About 180 million years after the Big Bang, the first stars began to burn through the fog of hydrogen around them. Cosmologists have been hunting for a signal from that transition, as the stars began to light up the surrounding neutral gas. The radiation from those forming stars also caused the gas to absorb energy from the omnipresent residual glow left over from the Big Bang, known as the cosmic microwave background (CMB).

That absorption happened at a particular frequency — 1.4 gigahertz, equivalent to a wavelength of 21 centimeters, which was subsequently stretched to some unknown lower frequency by the expansion of the universe. This past year, researchers announced they had finally found that absorption signal — except it doesn't look like what everyone had expected. And the differences have garnered a lot of criticism.

Scientists with the EDGES experiment, a radio antenna in the Australian Outback, reported February 28 in *Nature* that they had detected an absorption signal connected to the first stars. But their analysis uncovered a signal wider and deeper than theorists thought possible, meaning the absorption is stronger than expected, so some additional factor must be impacting the amount of energy absorbed. That factor could be a second radio background astronomers haven't considered yet, such as a population of black holes that emit radio light. Or maybe the original hydrogen in the cosmos was actually cooler than expected, therefore absorbing more heat than expected from the CMB.

In the months after the EDGES paper, several groups have released a wide variety of theories for the cause of the unexpected signal. As EDGES team member Raul Monsalve says, though, the EDGES group is "agnostic" about the interpretation of the signal. "We are focused on verifying our detection because everything rests on that, on the detection being solid," he says. They're working on further detections, while other groups with competing instruments are also looking for the same type of signal. Only after that can theorists truly begin breaking down the physics behind its cause.

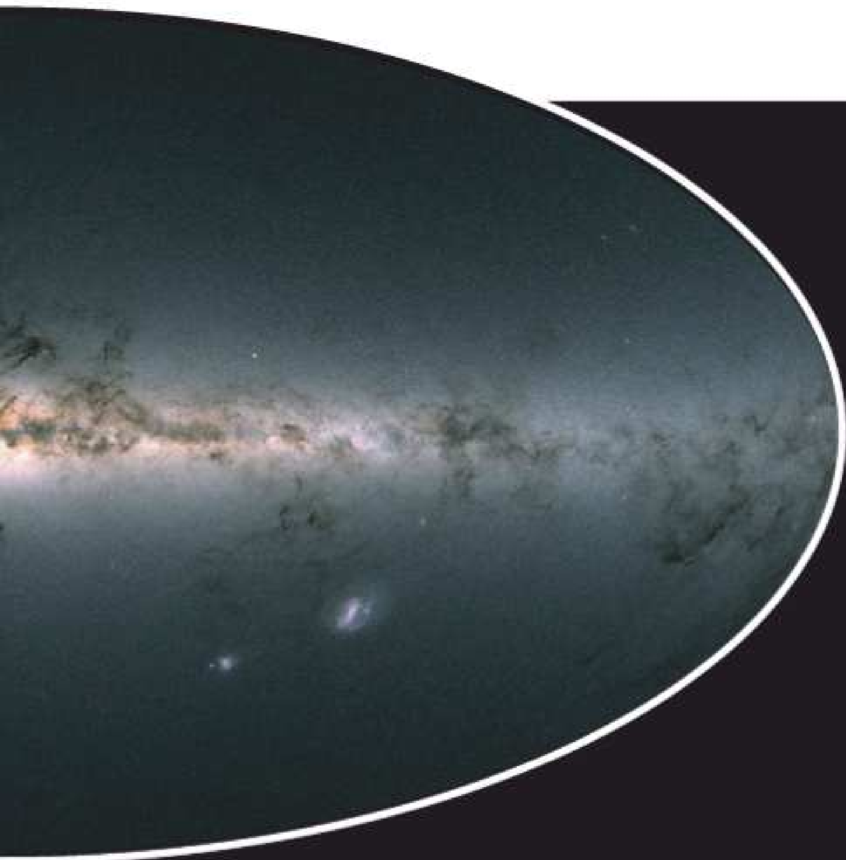


5 ASTRONOMERS MAP THE STARS IN 3D

IN DECEMBER 2013, THE EUROPEAN SPACE AGENCY LAUNCHED THE GAIA MISSION TO CHART THE HEAVENS — or, more scientifically, to map more than a billion stars in three dimensions. In April 2018, Gaia's second data release, DR2, went public, brimming with the positions, parallaxes, and proper motions of 1.3 billion objects.

One of Gaia's tasks is measuring the positions of the stars — and any other source of light — in the sky. The spacecraft detects anything bright enough that passes into its telescope's field of view, says Gaia Project Scientist Timo Prusti. "At that moment Gaia has no idea whether it's a star or a galaxy or an asteroid; we get it all," says Prusti. DR2 includes more than 1 billion stars, millions of galaxies, and some 300,000 asteroids.

But the most scientifically exciting aspect of DR2 is the measurements of parallax, "which is the annual wobble due to the Earth going around the Sun," says Prusti. To understand parallax, extend your arm and hold your thumb up. Close your right eye, and notice your thumb's position with regard to the background. Then open your right eye and close your left eye, noticing again your thumb's position. Your thumb appeared to move, right? That's the parallax effect, and if you had measured that movement very precisely, you'd be able to calculate how far your hand is from your face. It's the same idea behind Gaia's distance measurements. As the spacecraft orbits around the Sun, it takes a picture of the same field



The second data release, or DR2, from the Gaia satellite mission came in April. It includes information about the position, distance, and motions of nearly 1.3 billion objects. Astronomers are now using this exquisitely detailed chart of the heavens for a variety of studies, unlocking the secrets of objects both within our own Milky Way Galaxy and far beyond it. ESA/GAIA/DPAC

of stars from multiple viewpoints in its orbit. Software matches the objects that appear to shift between different photos and measures how much each moved with respect to the even more distant background stars, which don't appear to shift.

DR2 also includes information about the amount of blue and red light coming from those objects. For stars, that information is the first step in learning about their color, which tells astronomers their temperature. The next data release, which will come in 2020, says Prusti, will include more detailed photometry (brightness information) and spectroscopy (information about the light, spread out by wavelength).

Since the second batch of data was released, astronomers have used it to write hundreds of scientific papers. They've measured the motions of 75 globular clusters — gravitationally bound groups of thousands of stars — in the Milky Way and pinpointed the properties of one of our galaxy's oldest stars. Gaia also sees the brightest stars in nearby galaxies, like Andromeda, M33, and the Large Magellanic Cloud (LMC). Using those stars, astronomers have measured the LMC's rotation and constrained the motion of M33 relative to the Andromeda Galaxy.

The astronomical community is latching onto Gaia. Often when the Gaia team receives a question, there's another message tacked onto the end of the question, says Prusti. "They [say], 'Oh, by the way, the data [are] magnificent. Thank you very much.'"

4 EUROPA'S PLUME CONFIRMED

Jupiter's moon Europa, shown here in a high-resolution image from the Galileo mission, is covered with an icy shell that may hide a liquid ocean beneath. Researchers studying data from Galileo discovered evidence for a water vapor plume recorded in 1997 measurements of the moon's magnetic field. NASA/JPL-CALTECH/SETI INSTITUTE

IN MAY 2017, THE UNIVERSITY OF MICHIGAN'S XIANZHE JIA WAS AT A MEETING ABOUT THE NEXT MISSION TO THE JOVIAN MOON EUROPA, an ice-shell-covered water world that might have conditions ripe for life. One session covered recent observations from the Hubble Space Telescope that hinted at a plume of water ejected from a region just south of Europa's equator.

That sparked an idea. NASA's Galileo mission, which ended in 2003, flew by Europa 11 times. One flyby went right over the same area where Hubble had spotted signs of a plume. The December 1997 flyby was the closest approach Galileo made to Europa, flying 124 miles (200 kilometers) above the moon.

Jia, who studies magnetic properties of planets and their moons, and his colleagues dug up the two-decades-old Galileo data of Europa's magnetic field. They saw a sudden change in the magnetic field's strength and direction as the spacecraft passed over the area where the plume was discovered. "It's very abrupt, and it's very brief," lasting only three minutes, says Jia. Such a "bend" in the magnetic field can occur when material — such as water in a plume — becomes ionized (loses electrons), leaving a detectable mark on the magnetic field. At the same time the bend was detected, Galileo's Plasma Wave Spectrometer instrument, which measured waves caused by charged particles around the moon, also detected a sudden rise and then drop in these particles.

Water itself is neutral, but Europa orbits Jupiter within the giant planet's magnetosphere. The planet's intense magnetic field, along with solar radiation, could ionize some of the particles in a plume, causing the observations Galileo recorded. At least, that's what Jia believed.

"But to really make sense of the observations in a quantitative way," says Jia, "we [had] to conduct sophisticated modeling" to determine whether a simulated plume could reproduce the observations. That type of modeling is what Jia and his group at the University of Michigan have been working on for the past several years. When they generated a plume based on Hubble data and Jupiter's magnetic environment, the model and the 20-year-old magnetic field data from Galileo agreed, showing that a plume reaching 120 miles (200 km) from the moon's surface could be what the spacecraft observed.

So what does this mean for future Europa exploration? When the next craft, called Europa Clipper, gets to the jovian moon, it won't need to drill into the ice shell to test the subsurface ocean for signs of life. Instead, it could fly through a plume and sample the liquid in its path.

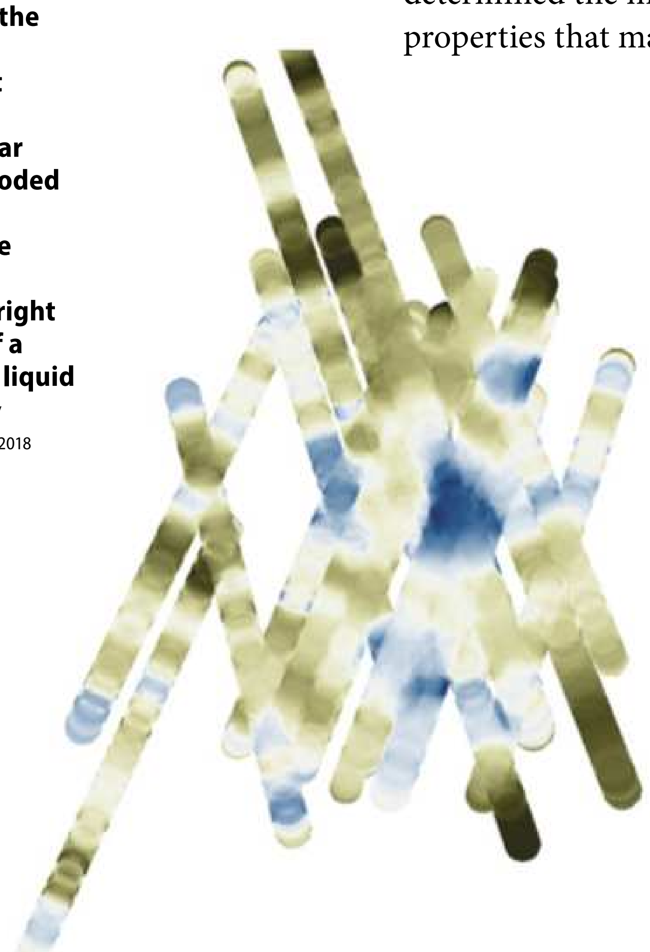
3

IN 2007, THE MARS ADVANCED RADAR FOR SUBSURFACE AND IONOSPHERE SOUNDING (MARSIS) INSTRUMENT on the Mars Express spacecraft detected stronger-than-expected echoes from beneath the planet's southern ice cap. MARSIS sends pulses of radio waves to the martian surface and then awaits the return of those pulses. The instrument measures the return time and the strength of the returned signal. The strong echoes meant the radio waves were hitting something reflective, which bounced a large amount of the signal back up to the spacecraft. But it took a decade of additional observations and new analysis techniques to reveal the source of the reflections: a lake of liquid water below the surface.

The key was finding a way to bypass the onboard computing system and analyze the raw data from Mars Express, says MARSIS principal investigator Roberto Orosei. The spacecraft, which was launched in 2003, utilizes technology from the 1990s. The onboard system had to reduce the data volume — and thus its quality — to process it on the spacecraft before sending the information back to Earth. "It turns out this was erasing information," which affected scientists' ability to tease out important details, says Orosei. Luckily, engineers had installed a few extra memory chips prior to launch. Orosei and his colleagues were able to use those extra chips "to record echoes before they were processed by the instrument CPU. When we were able to download even a small number of raw data, data before processing," says Orosei, they had "clear detections, and repeatable measurements, of strong echoes" in small areas.

That was in May 2012. Over the next three and a half years, Mars Express flew over the same site some 30 times, allowing MARSIS to study that region in overlapping passes. Each time, the radio waves passed through the ice at the polar cap and hit something reflective before bouncing back to the spacecraft. The reflection was stronger than reflections off the surface of the planet, so it had to be a different material. But what?

MARS HAS AN UNDERGROUND LAKE



The MARSIS instrument on Mars Express sent radio waves to the planet, observing the echoes it received to determine what lay beneath the ground. These radar footprints, color-coded to the strength of the reflection (blue indicates brighter regions), show a bright patch indicative of a subsurface lake of liquid water. ESA/NASA/JPL/ASI/ UNIV. ROME; R. OROSEI ET AL. 2018

The researchers knew the thickness of the ice at the polar cap, but they didn't know other factors that would affect the reflectivity, such as how much dust might be within the ice. They also didn't know the temperature at the bottom of the ice, or the material that lay below it. To solve the mystery, they turned to computer models, "turning the knobs and changing the values of the parameters," says Orosei. To reproduce the data, his team determined the material reflecting the signals must have properties that matched liquid water.

They argue, based on the findings published in their July *Science* paper, that the source is a lake of liquid, salty water about 1 mile (1.5 km) below the icy polar cap. Furthermore, the 12-mile-wide (20 km) lake must be at least 3 feet (1 m) deep because the MARSIS instrument can't make out smaller details than about that size.

The finding is not readily accepted by all, though. Some researchers, for example, say the higher-than-expected reading may be due to scattering effects. To reinforce their finding, says Orosei, they need to find more of these bodies of water. "We keep observing because we hope to find more lakes," he says, "and we have hints this might be the case, but we need to do much more work on that."

'Oumuamua became the first known interstellar interloper when it was detected swooping around the Sun. On its way out of the solar system, the object displayed motion that astronomers believe is associated with outgassing — cometary activity. Though difficult to model, 'Oumuamua is likely elongated in shape, as shown in this artist's concept.
NASA, ESA, AND J. OLMSTED AND F. SUMMERS (STScI)

INTERLOPER FROM ANOTHER STELLAR SYSTEM

2

OCTOBER 22, 2017, WAS KAREN MEECH'S FIRST DAY OFF IN MONTHS. The University of Hawaii astronomer had just returned home from a planetary science conference, and she was looking forward to a Sunday to relax. Then the phone rang. It was her colleague Richard Wainscoat, with news that the 1.8m Pan-STARRS Telescope had just made a big discovery: An interloper in our solar system from another planetary system had been found. To learn more about the object, more observations were needed, and they needed to be taken quickly. "I was excited, and then I thought: Did it really have to be today?" she says with a laugh.

Pan-STARRS was built to catch transient objects in the sky — things like exploding stars and moving comets. The telescope spotted such an object October 19. Robert Weryk, a postdoctoral researcher at the University of Hawaii, was on duty the morning of October 20, looking for moving objects in the previous night's observations. He saw a light trail, which corresponds to a speeding object in images. Weryk looked at the observations from the night of October 18 to compare, and there it was again. This object was moving west at 6.2° per day; for it to move so fast, it must be close to Earth. Over the next few days, the Pan-STARRS team used a few other telescopes to observe the object and map out its orbit. They realized on October 22 its orbit didn't originate in our solar system and is not a closed loop. After it swung around the Sun, it would never return.

That's when Meech got the phone call.

Over the next week, Meech and her colleagues used telescopes in Chile and Hawaii to capture as much information about the interloper, named 1I/2017 U1 ('Oumuamua; Hawaiian for "scout"), as quickly as possible. Just over a week later, they submitted their discovery paper to *Nature*. That first paper was printed in late 2017, but several more, with further details, have followed.

The team now knows 'Oumuamua's orbit and its brightness. The brightness depends on how far it is from Earth and the Sun, as well as how reflective the surface is. We don't know that last detail, so scientists use a reflectivity of 4 percent — the reflectivity of comets in our solar system. Meech and her colleagues saw that 'Oumuamua's brightness varied by a factor of 10 over several hours, so they concluded it must be an elongated object. They estimate it is about 2,600 feet (800 m) long and about 260 feet (80 m) wide, and perhaps cigar-shaped.

That variation in brightness, though, isn't a simple periodic relation. Instead, 'Oumuamua seemed to have a complex rotation, tumbling through space around all three axes. That rotation is actually quite strange. "It has so-called non-gravitational motion, which we typically see with comets because they have outgassing that acts like a little rocket thruster that changes the orbit," says Meech, "yet no one detected any gas or dust." Perhaps the dust grains being dragged off during the outgassing were a size not visible in the particular wavelengths of light the scientists studied.

Another strange characteristic of 'Oumuamua is its chemistry. A few groups managed to obtain spectra, and because each chemical element has a specific fingerprint of light, researchers can identify which elements are at the object's surface based on what they see. Those same elements are dragged off the surface during outgassing. But the researchers didn't see the normal chemicals that are common in other comets. "That means it's got slightly different chemistry than comets in our solar system," says Meech.

A planetary system around another star would form out of a different clump of gas and dust than ours, meaning its chemical composition would be distinct from that of the solar system. "We had a piece of material delivered close to us from another solar system," says Meech. And now that they know what to look for, astronomers are eagerly scanning the sky for the next interstellar interloper.

THE FASCINATING CASE OF THE NEUTRINO AND MULTI-MESSENGER ASTRONOMY

1

SEPTEMBER 22, 2017, STARTED THE SAME AS ANY OTHER DAY FOR PHYSICIST FRANCIS HALZEN, the leader of the IceCube project, the cubic-kilometer-sized neutrino detector embedded deep within the Antarctic ice.

Neutrinos are high-speed, neutrally charged particles that typically pass through our planet unimpeded. But a small percent of neutrinos interact with matter, such as the ice, and IceCube detects the secondary signals of their interaction. An alert is generated automatically when IceCube detects a signal; this alert is sent out to worldwide observatories for follow up. That fall day, Halzen received an email 43 seconds after a neutrino generated a secondary particle that passed through the detector. But nothing about the detection seemed extraordinary.

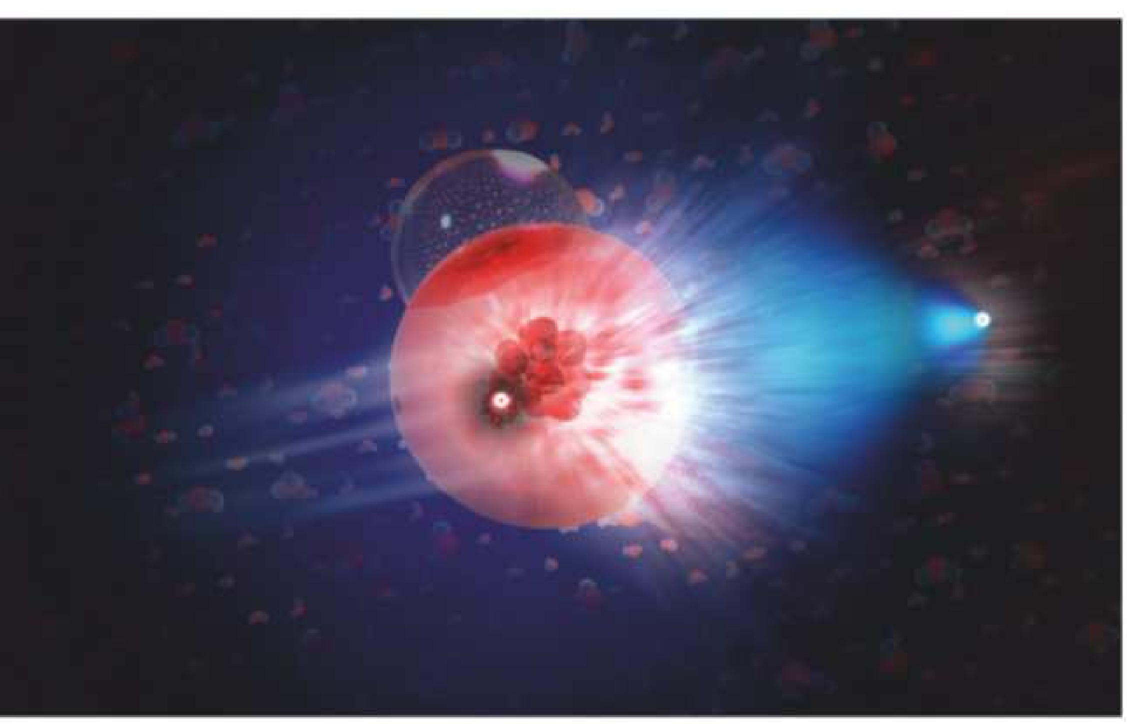
A few days later, he and his colleagues began to hear of an active galaxy 4 billion light-years from Earth flaring in the same portion of the sky their neutrino had come from. No neutrino had ever been traced back to a source outside our galaxy before, but theorists believed that active galaxies like this one could be a source of these particles. Now, the Fermi Gamma-ray Space Telescope had seen a galaxy give off a burst of gamma rays that coincided with the detection of a neutrino. Could the neutrino also have come from that galaxy?

The IceCube team calculated the likelihood, but it wasn't a high probability. It was "nothing to get excited about," says Halzen.

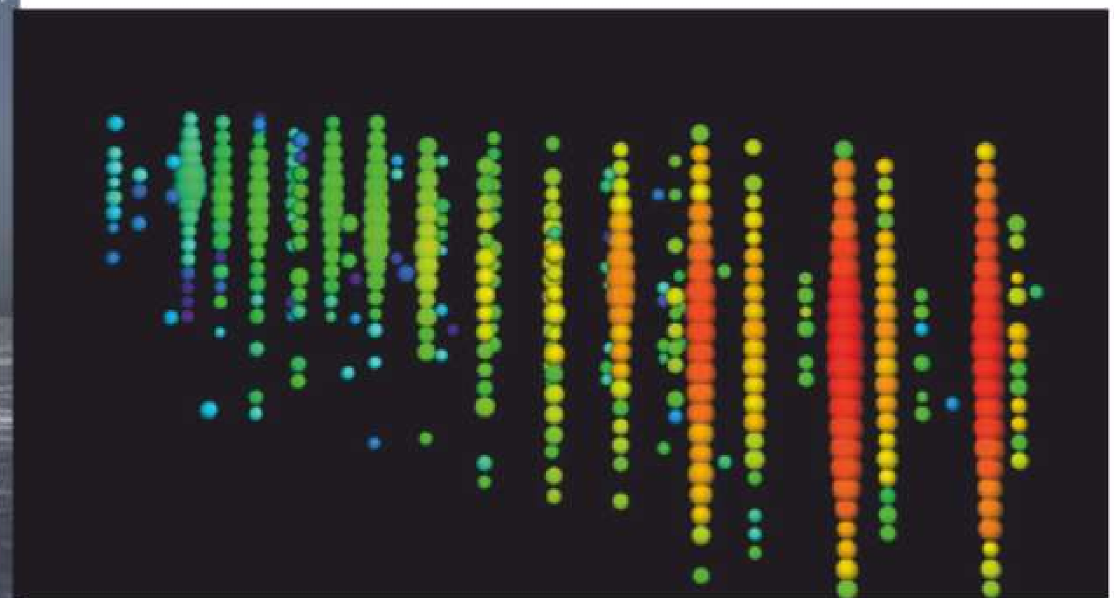
Members of the IceCube team continued to look into archived data of the same region of sky. They found that more than a dozen neutrinos originating from the location of that active galaxy had traversed the detector between late 2014 and early 2015. "That was the exciting moment, when I saw those events," says Halzen. In late 2017, the scientists dove into a thorough analysis of the data from IceCube, Fermi, the ground-based Major Atmospheric Gamma Imaging Cherenkov Telescope (MAGIC), and about a dozen other X-ray, optical, and radio telescopes. "During Christmas, I was in the middle of this [analysis]," says Halzen.

In July 2018, the hundreds of scientists published their findings in *Science*: The neutrinos were coming from that galaxy, named TXS 0506+056. The galaxy is classified as a blazar because the supermassive black hole at its center is generating a pair of perpendicular jets, one of which is pointed directly at Earth. These powerful jets spew radiation and energetic particles, including the neutrinos captured by the IceCube detector.

The same processes that generate neutrinos can also energize electrons and positrons to the highest energies — these are known as cosmic rays. Since 1912, scientists have known Earth is bombarded by cosmic rays with energies higher than anything physicists can produce in the lab. But they don't know where exactly these cosmic rays come from. As electrically charged positrons and electrons travel through space, they are buffeted by cosmic magnetic fields, so they don't travel in straight lines.



Below: When a neutrino strikes a molecule in the Antarctic ice (red), the collision generates a particle called a muon (blue), as seen in this artist's concept. The muon streaks on at relativistic speed in a flash of blue light, allowing the IceCube detectors to register its motion. NICOLLE R. FULLER/NSF/ICECUBE



Left: The IceCube lab at the South Pole, seen in this artist's concept, sits atop an array of sensors designed to detect the byproducts that occur when a neutrino interacts with an atom in the ice. MARTIN WOLF, ICECUBE/NSF

Above: When a neutrino from the blazar TXS 0506+056 struck the Antarctic ice, IceCube's detectors sensed the muon it generated as a result. This computer-generated image shows the sensors that detected the muon on September 22, 2017; the color gradient represents time, from red to green and blue. ICECUBE COLLABORATION

But neutrinos and gamma rays have no charge and can continue on straight paths, directly from their source to Earth. With the identification of a neutrino source, astronomers can now also piece together where some of the cosmic rays we receive at Earth come from.

The armada of telescopes that studied TXS 0506+056 and the hundreds of scientists who analyzed that data confirmed that active galaxies accelerate the highest-energy cosmic rays. Without collaboration among different observatory groups looking at different types of light and particles, "this would have been just one more neutrino," says Halzen. "This is a discovery that is not possible without multi-messenger astronomy," he says. We've entered a new era of astrophysics that incorporates not only gravitational waves (the story that topped last year's top 10 list), but now also particles from other galaxies.

Liz Kruesi *is a frequent contributing author to* Astronomy. *She currently writes about the stars from her home in Austin, Texas.*

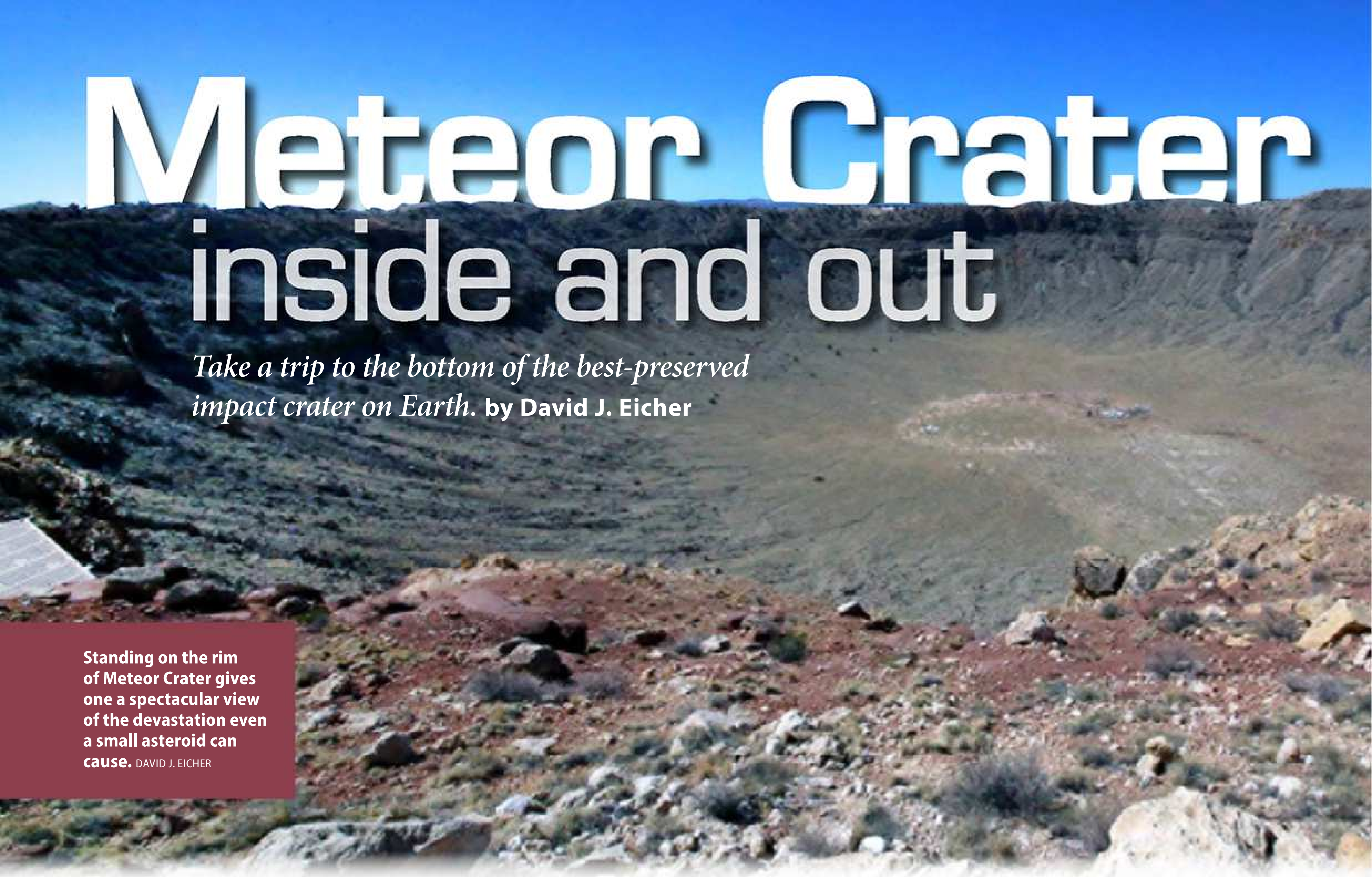
STORIES TO WATCH FOR IN 2019

- The New Horizons spacecraft is scheduled to make its closest approach to the possibly binary Kuiper Belt object nicknamed Ultima Thule shortly after midnight January 1, 2019.
- Astronomers and the public alike are eagerly awaiting the first image of a black hole's event horizon from the Event Horizon Telescope. The collaboration hopes to release an image in 2019.
- NASA's first crewed spaceflights of commercial capsules developed by Boeing and SpaceX are expected to begin in spring or summer 2019.
- The Indian Space Research Organisation's second Moon mission, named Chandrayaan-2, is slated to launch between January and March 2019.
- Japan's Hayabusa2, currently exploring the asteroid Ryugu, is set to leave the asteroid on its return trip to Earth with samples of the surface by December 2019.

— Alison Klesman

Meteor Crater inside and out

Take a trip to the bottom of the best-preserved impact crater on Earth. **by David J. Eicher**



Standing on the rim of Meteor Crater gives one a spectacular view of the devastation even a small asteroid can cause. DAVID J. EICHER

WITH THE START OF THE 50TH ANNIVERSARY of the legendary Apollo missions, you might find yourself dreaming about what it would have been like to explore lunar craters up close. Well, there's a pretty good way to live that dream right here on Earth: Meteor Crater, the world's most famous impact scar, lies on the Arizona plain about 18 miles (29 kilometers) west of Winslow — you know, that town from the Eagles' song.

The crater attracts some 270,000 visitors per year, but rarely do visitors get the chance to climb down to the crater's floor and explore the whole thing. However, this summer, I got the chance to trek into Meteor Crater along with the site's owner, Drew Barringer, whose family has owned Meteor Crater since 1903, and a small group led by planetary scientist David Kring of the Lunar and Planetary Institute in Houston. The journey afforded us a unique, eye-opening view of what even a small asteroid can do to our planet.

The best crater on the planet

About 4 billion years ago, the inner solar system was repeatedly battered with asteroids, planetesimals, and comets. To see the evidence of this period — called the Late Heavy Bombardment — you only need to look at the ancient scars on the Moon or Mercury. Earth was not exempted from this aerial attack, but our planet has a widespread system of resurfacing, thanks to plate tectonics, volcanism, wind, water, and so on.

Yet we know many impacts have taken place on our world in its past. Famous among them is the K-Pg impact near Chicxulub in the Yucatán Peninsula, which wiped out a high percentage of species, including the dinosaurs, some 66 million years ago. More recently, smaller impacts come to mind, such as the Tunguska event, an airburst explosion over Siberia in 1908; and the Chelyabinsk blast over Russia in 2013.

And then there's Meteor Crater, the first proven and best preserved of all Earth impact craters.

Located some 185 miles (300 km) north of Phoenix, Meteor Crater is unlike any other spot on Earth. Perched at an elevation of 5,710 feet (1,740 meters) above sea level, the impact scar stretches three-quarters of a mile (1.2 km) across, and the floor is 560 feet (170 m) deep. The crater's rim has a circumference of 2.4 miles (3.9 km) and rises 148 feet (45 m) above the surrounding desert plain.

The journey downward

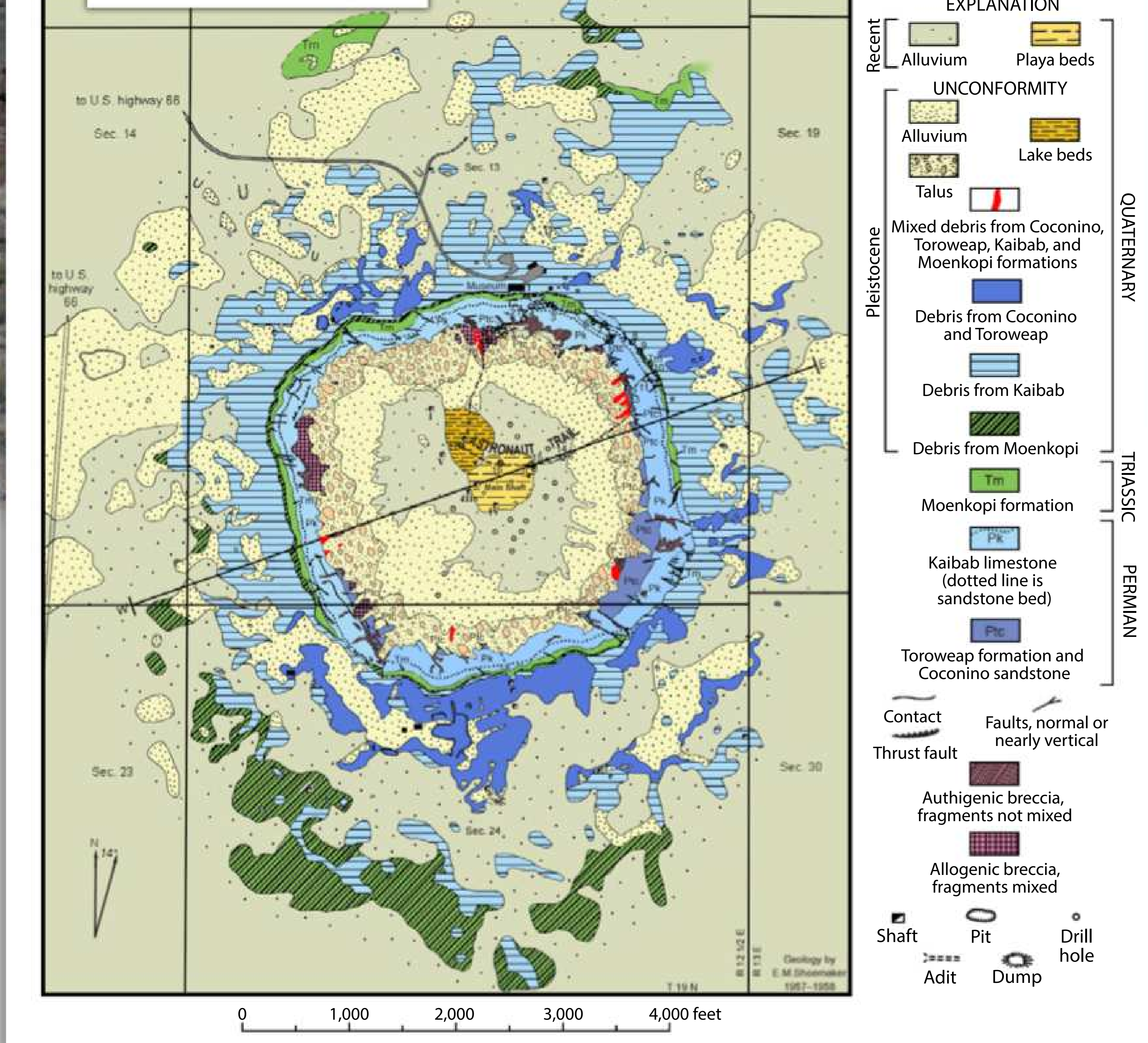
Our group started hiking into the crater on a sweltering day, when the temperature tipped the scales at 95 degrees Fahrenheit (35 degrees Celsius). Other members of our group were well acclimated to the altitude; I was not, having come from an elevation of only 800 feet (240 m) in Wisconsin just two days earlier. The difference in altitude of nearly 5,000 feet (1,500 m) and the Arizona heat would come back to haunt me later in the journey.

After our group assembled, we went through the beautiful visitor center and headed west along the crater rim trail, which led to a century-old trail into the crater.

One of the first things we noticed as we climbed down was to turn our heads back up to see the crater's raised rim, as well as

LEFT: An overhead view of Meteor Crater shows the roughly 1.2-kilometer diameter and its somewhat square appearance, caused by corners that are associated with geological tear faults. Remnants of mining operations are visible in the center of the crater floor. The Visitor Center and Museum are visible at top, above the rim. DAVID KRING

BELOW: This geologic map of Meteor Crater was produced by planetary scientist Gene Shoemaker in 1960. In addition to identifying different varieties of bedrock, Shoemaker mapped the interior deposits of breccia, exterior areas of debris, and faults that cross-cut the crater walls. DAVID KRING



the enormous blocks of uplifted rock above us that had been thrown out of the crater. Kring also showed us close-up views of some white Coconino Sandstone, the plentiful sedimentary rock made almost entirely of finely ground quartz that serves as the lowest layer of the upper portion of the native landscape.

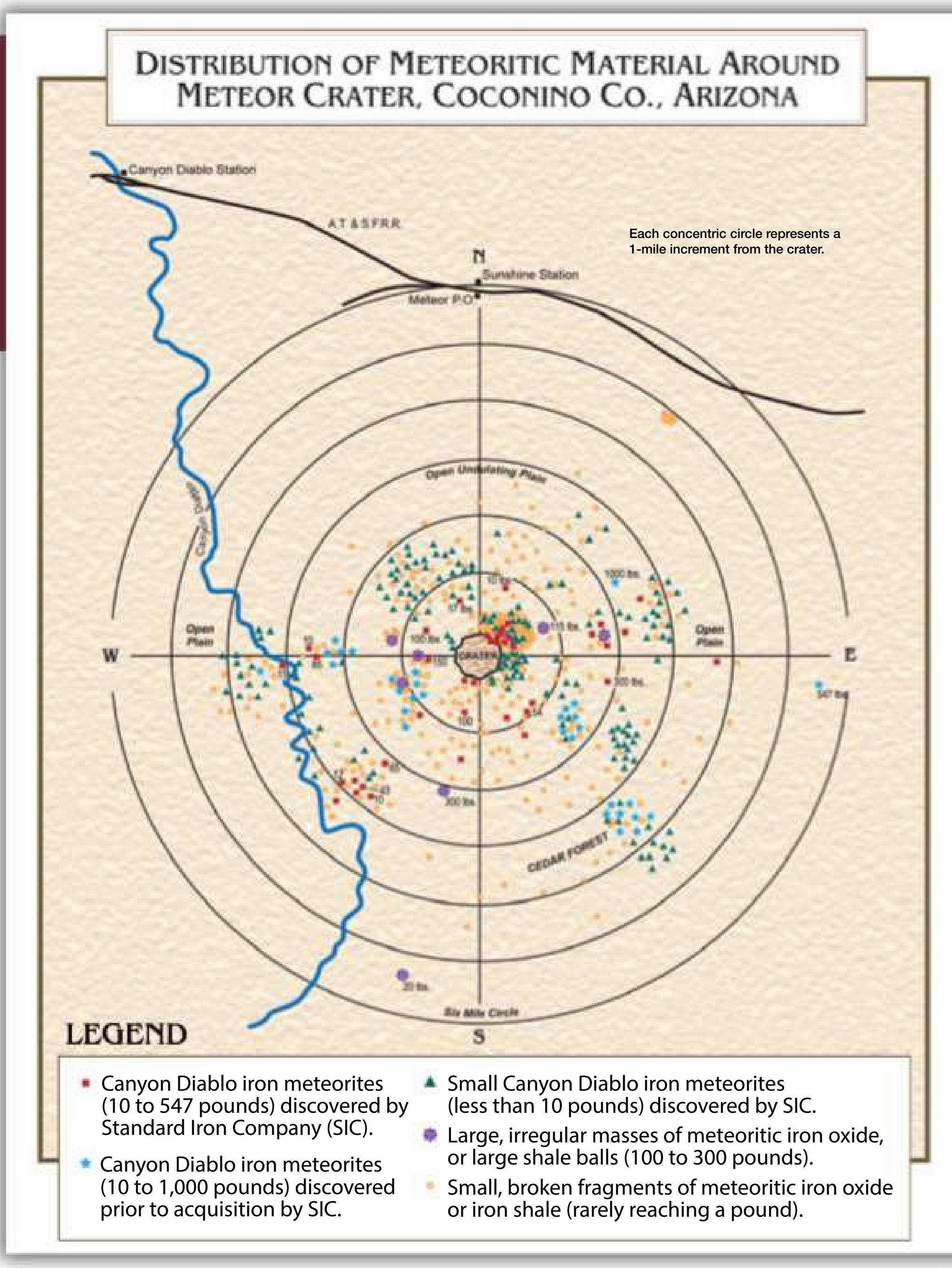
Other types of rock are also exposed in the crater walls. They include the Toroweap Formation, a thin layer of sandstone and dolomite rising above the Coconino; and above that, the Kaibab Formation, a thicker layer of dolomite, dolomitic limestone, and thin sandstone. This represents a time when the area was covered by a sea, one that deposited abundant fossils within these layers, with some dating back more than 250 million years. Lastly, there is the reddish siltstone Moenkopi Formation, closest to the surface.

Crater geology

As we stopped to rest during our slow, winding, and astonishingly hot journey downward, Kring continued to regale us with background on the crater's structure. In 1960, Gene Shoemaker produced the definitive geological map of Meteor Crater. His work demonstrated that the upper crater walls and uplifted crater rim are composed of Coconino, Toroweap, Kaibab, and Moenkopi formation rocks. Its simple bowl shape is typical for impact craters less than roughly 1.25 miles (2 km) in diameter in sedimentary rock, or smaller than 2.5 miles (4 km) in crystalline targets. Meteor Crater has no features of large craters visible on the Moon, such as central peaks or rings, but it does have so-called tear faults that cross-cut the terrain in four areas, giving the crater its squarish appearance.

Debris is scattered both around the crater's perimeter and within it, too. Geologists have a special term for rock that has been smashed, mixed up, and fused back together like this: breccia. Atop the brecciated rock on the crater's floor lie ancient lake

This 1908 map of the distribution of Canyon Diablo meteorite specimens, published in 1910 by Daniel Moreau Barringer, shows where major meteorite finds were made around the crater.
DAVID KRING



sediments that have commingled with material shedding downward from the crater walls. After the impact, the environment in this area became far more arid, and the lake evaporated, leaving the mixed-in debris behind. Because of this, the floor of the crater is now well over 100 feet higher than it stood just after the impact.

It's clear why astronauts were brought here for training, first by Shoemaker and now by Kring. The landscape certainly offers a challenging, lunarlike environment to climb into, one that is well suited for testing astronaut durability.

Marching toward the center

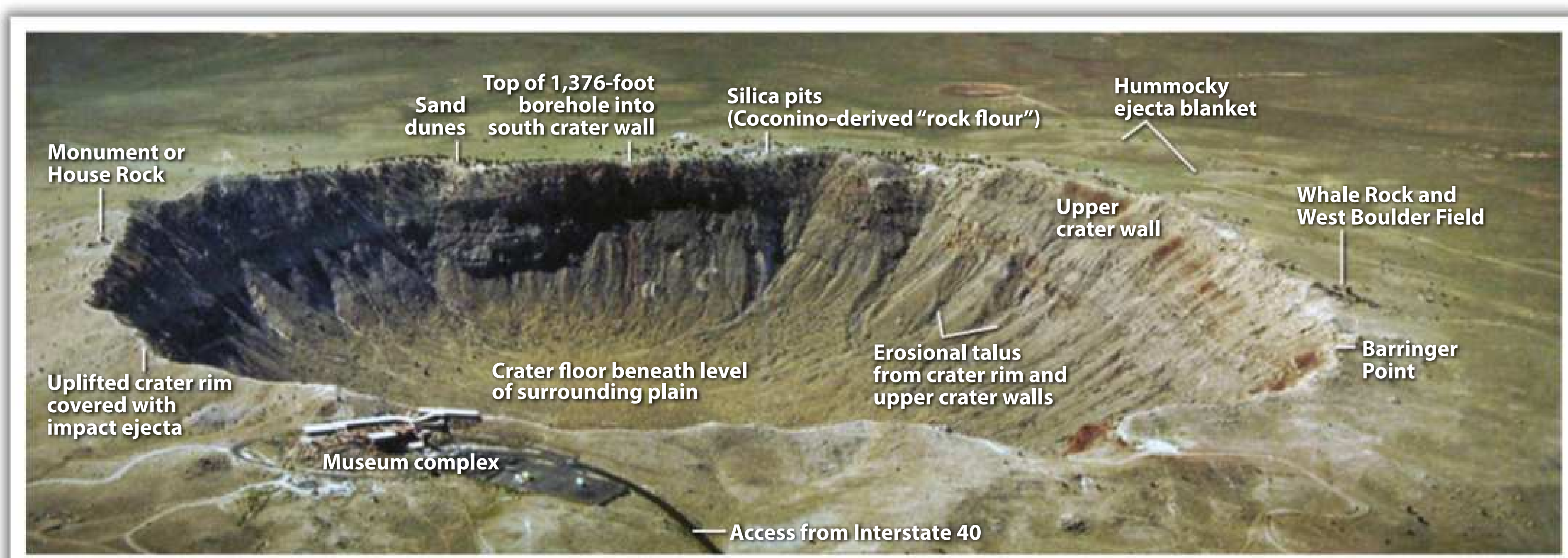
As we traversed the crater floor, Kring described how an analysis of shock metamorphism helped prove the crater was an impact. In the first decade of the 20th century, Drew Barringer's grandfather, Daniel Moreau Barringer, discovered "rock flour" — pulverized Coconino sandstone. Later, geologists identified the mineral coesite, a high-pressure form of quartz, in the crater. And soon after, they identified stishovite, another high-stress form of quartz, which clearly indicated the great pressure that was unleashed with the impact.

As we walked along, Kring described how the impact uplifted the crater rim, as evidenced by the layers of the crater walls. Fracturing within the crater walls bulked up the rock, while broken rock fragments and ejecta filled in parts of the walls, helping to preserve them.

But, Kring explained, the ejecta forming the crater walls were hardly all of the material cast out from the impact. Rubble from the meteorite strike lies over a radial reach of more than a mile (1.5 km) from the crater's center. The largest pieces sit near the crater rim, where massive blocks of limestone and sandstone weighing up to 5,000 tons were thrown. Some smaller blocks of rock that landed a third of a mile (0.5 km) beyond the rim likely hit velocities of nearly 225 mph (370 km/h).

When we reached the central point of the crater floor, Kring reviewed the current thinking on the impactor. The meteorite likely had a diameter of about 160 feet (50 m) before its main mass was obliterated by the incredible energy released in the impact. Fragments of the iron-nickel meteorite, known as Canyon Diablo, have been picked up since prehistoric times, and the estimated total mass recovered is something like 30 tons — but that's a crude guess. The meteorite is composed of primarily iron with about 7 percent nickel and a small percentage of other elements.

It's an amazing thing to stand in the middle of the crater and look all around at the walls towering on all sides. Looking upward, you could begin to imagine how the asteroid barreled in. Though the incoming trajectory of the asteroid remains



DAVID KRING/COURTESY OF METEOR CRATER ENTERPRISES

unknown, we do know something of the immense energy released by the impact. Assuming a roughly 160-foot (50 m) object with a mass of about half a million metric tons, the incoming speed of the asteroid would have been somewhere in the range of 7 to 12 miles per second (11 to 20 km/s). Physicists estimate the impact energy released at roughly 10 megatons, or 700 times the energy of the atomic bomb that exploded over Hiroshima.

The incredible force unleashed by this impact shook the immediate area, as well as the surrounding region. The impact ejected debris from the site and produced a fireball, a radiating shock wave, and a related air blast.

Plants and animals at the impact site would have been vaporized, while those over a 20-mile (32 km) region would have been killed or injured by the shock wave. The air blast would have produced winds far greater than hurricane force, sending rocks, tree branches, and other debris flying outward like missiles. The ballistic shock wave would have created injuries, perhaps many fatal, over a much larger area yet.

The climb back up

As he had said several times when we began our long hike, Kring reminded us to take it easy and hydrate substantially before we left the crater floor. "There are two ways back out," he told us. "You can climb, and so you need to take care of your body. Or you can be taken out by helicopter. That costs about $10,000, and I'm not going to pay for it."

As we approached the edge of the floor, we started our upward journey along the antique trail, still thinking about the incredible blast. Kring then shifted the focus of his lecture to the one missing piece of the story: When did all of this occur? As it turns out, the thinking about the age of the impact has been changing recently.

The earliest experts thought the crater so well preserved that it couldn't be fantastically old. But finding the crater's age is a tough process, in part because the crater is young enough that many radiometric techniques for dating rocks are ineffective.

Daniel Barringer initially believed the crater to be between 2,000 and 3,000 years old. But in the 1930s, geologist Eliot Blackwelder of Stanford University examined the thickness of lake sediments on the floor, debris on the crater slopes, pitting of ejected limestone, and other factors to estimate an age of 40,000 to 75,000 years. In the 1980s, Stephen R. Sutton of the University of Chicago measured the amount of accumulated radiation and found an age of 49,000 years, plus or minus a few thousand. More recent studies have agreed with that figure. However, Kring says studies currently in the press may push the age of the crater to around 60,000 years or slightly older — so stay tuned.

A coarse octahedrite Canyon Diablo meteorite. ROBERT HAAG

As we continued ascending the crater's steep slope, I felt more and more winded, and then a bit lightheaded. You guessed it: The guy from the Midwest had heat exhaustion. I attempted to soldier on, but as we neared the bottom of the rim, about to make our way out, I finally got sick. I threw up in Meteor Crater. It wasn't my finest hour. And although I had learned a great deal of compelling information about the crater, in one sense, the heat won the day.

Lessons for the future

As mentioned, the impactor that made Meteor Crater was a relatively small asteroid from an ancient planetesimal. Other such impacts have frequently taken place on Earth, and their scars have faded away, but in the Arizona desert, with an impact just 60,000 or so years old, the scar remains.

Planetary scientists are frantically working on expanding their inventory of near-Earth objects (NEOs), asteroids that could (and will) impact our planet in the future. Fortunately, there are no large objects in near-Earth space similar to the K-Pg impactor.

But what about small asteroids that could devastate entire cities or regions, like the asteroid that made Meteor Crater? Astronomers now know of about 18,500 NEOs, but the inventory of objects down to 160 feet (50 m) in size is complete only to an estimated 1 percent. Yes, that's 1 percent.

So, watch out for space rocks!

David J. Eicher *is editor of* Astronomy *and a big fan of Meteor Crater.*

Check out an extended version of this story, as well as additional images, at www.astronomy.com/bonus/crater.

Learn more about another incredible astronomical site in Arizona, Lowell Observatory, on p. 44.

A BRIEF HISTORY OF METEOR CRATER

The story of Meteor Crater begins in 1891, with Philadelphia mineralogist and mineral dealer A.E. Foote (1846–1895), who heard about the crater after receiving a sample of iron from the site. Foote analyzed the sample and found it contained signature minerals and elements — such as troilite, daubréelite, carbon, and diamonds — of extraterrestrial origin. This led him to write and present a scientific paper at a meeting of the American Association for the Advancement of Science in Washington, D.C.

In attendance at Foote's lecture was Grove Karl Gilbert (1843–1918), chief geologist of the U.S. Geological Survey. He was entranced by the story of the crater and its meteoritic iron. Gilbert conducted his own measurements in late 1891 to attempt to pinpoint meteoritic material underneath the crater, and after detecting no magnetic signature, he concluded the crater had formed from a massive steam explosion, not a meteorite strike.

Unaware of this primitive geological work, geologist Daniel Moreau Barringer (1860–1929) learned of the crater and dreamed of finding lucrative iron and nickel contained within the meteorite mass. In 1903, he acquired the crater through a series of mining claims, and although the site is more commonly known as Meteor Crater, its proper scientific name is still Barringer Meteorite Crater.

Unlike Gilbert, Barringer carefully studied the distribution of the meteoritic iron and found that pieces were scattered concentrically around the crater. He also described how uplifted strata in the crater walls were well explained by a forceful impact, and how the largest ejected blocks were oriented in an east-west line, which suggested the trajectory of the impacting body. Because a steam explosion seemed out of the question, Barringer concluded the crater must have been the result of an impact from space.

A mountain of additional confirming evidence came later from the work of Gene Shoemaker (1928–1997), geologist and one of the founders of planetary science. In 1960, Shoemaker incorporated novel studies of nuclear blast explosions and developed a new model for understanding high-speed, energetic impacts. Shoemaker's studies confirmed what Barringer believed: The crater was definitely from a meteorite. — *D.J.E.*

MARTIN RATCLIFFE and **ALISTER LING** describe the solar system's changing landscape as it appears in Earth's sky.

Visible to the naked eye
Visible with binoculars
Visible with a telescope

January 2019: Totality over America

The orange glow from all Earth's sunrises and sunsets painted the Moon during the September 28, 2015, total lunar eclipse. Observers across the Americas should get a similar view the night of January 20/21. JOSÉ J. CHAMBÓ

A total eclipse of the Moon is a highlight in a month that also features exceptional views of several planets. While the fainter worlds gather in the early evening sky, the more luminous ones congregate before dawn. Skywatchers should mark their calendars for the morning of the 22nd, when the two brightest planets, Venus and Jupiter, pass just 2° from each other.

Let's begin our tour of the night sky with its top event: the total lunar eclipse. Observers under a clear sky across North and South America can watch the Full Moon fade and change color as it slides through Earth's shadow the night of January 20/21.

The eclipse gets underway the evening of the 20th. Luna enters our planet's outer penumbral shadow at 9:37 P.M. EST. The penumbra's subtle shading initially has little effect on the Moon, but viewers should see the lower limb start to darken within a half-hour.

The partial eclipse officially begins at 10:34 P.M., when our satellite encounters Earth's inner umbral shadow. No direct sunlight enters the umbra, so you might expect the shadow to look black. And it does, at least at first. But as the Moon dives deeper into the shadow and totality approaches, it takes on a distinct orange glow. The color comes from all Earth's sunrises and sunsets — our planet's atmosphere bends this light into the shadow.

The color becomes even more noticeable during the 62 minutes of totality, which commences at 11:41 P.M. The eclipsed Moon is mesmerizing however you view it, but be sure to enjoy the surrounding sky. As the eclipse progresses, the sky darkens and the star-studded winter sky blossoms into view. Binoculars will reveal the attractive Beehive star cluster (M44) just 7° east of the Moon.

The total phase of the eclipse ends at 12:43 A.M., and the Moon exits the umbral shadow at 1:51 A.M. The final trace of the penumbra leaves the lunar disk without fanfare at 2:48 A.M. Don't pass up the opportunity to see this total lunar eclipse — you'll have to wait until May 2021 for the next one.

While the Moon glows orange only one evening this month, **Mars** shows a similar color every January night. The planet appears about halfway to the zenith in the southwest as darkness falls. It remains on view until it dips below the western horizon after 11 P.M. local time.

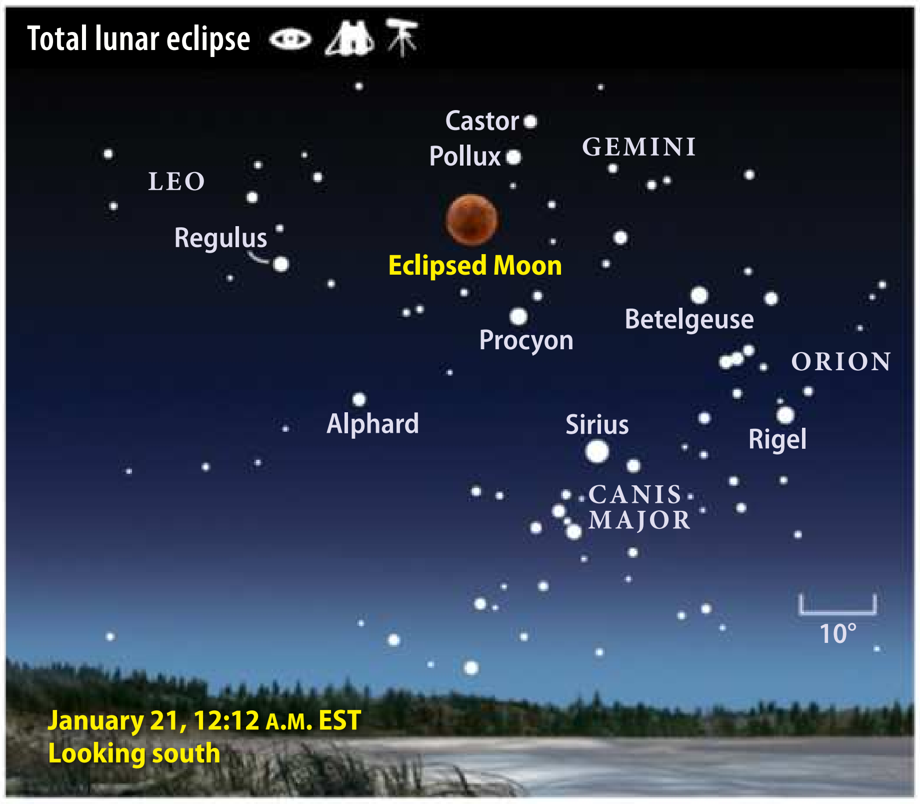
Mars stands out against the relatively dim background stars of Pisces the Fish. It shines at magnitude 0.5 in early January and fades to magnitude 0.9 by month's end, though that's still more than 10 times brighter than any of the constellation's stars.

The planet begins the month southeast of Pisces' Circlet asterism, a distinctive grouping that lies due south of the Great Square of Pegasus. The ruddy world then treks eastward rapidly. It slides 0.9° south of 4th-magnitude Epsilon (ε) Piscium on January 26.

Despite Mars' prominence to the naked eye, it doesn't offer much to observers with telescopes. The planet continues to move away from Earth and thus shrink in size. Its apparent diameter holds at 7" during the first half of January but drops to 6" by month's close. You'll need excellent viewing conditions to see it as anything more than a featureless disk.

Mars serves as a guide to finding Uranus and Neptune this month. The two conveniently bracket the Red Planet and glow brightly enough to show up through binoculars.

You'll want to hunt for **Neptune** first. It lies west of Mars and thus hangs lower in



The eclipsed Moon hangs just below the twin stars Castor and Pollux in Gemini at midtotality January 20/21. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

RISING**MOON**

When second best is still fine

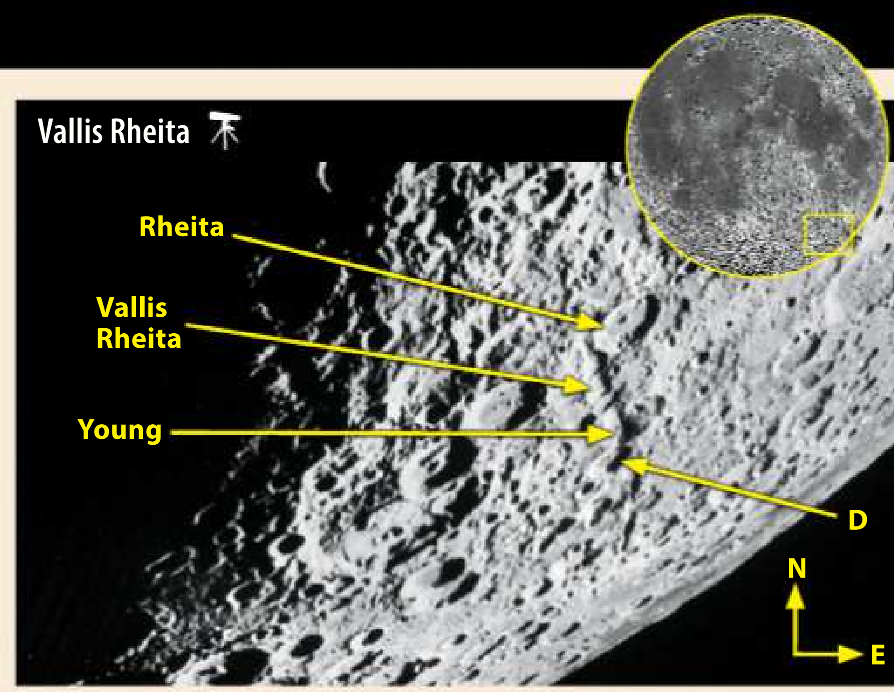
Only about a dozen major lunar valleys appear on the Moon's nearside. Most observers consider Vallis Alpes (Alpine Valley) in the north to be the best, but Vallis Rheita (Rheita Valley) in the southeast runs a close second.

The two are a study in contrasts. The Alpine Valley arose when the lunar crust pulled apart and the land collapsed. The Rheita Valley formed as a line of overlapping craters. The impacts occurred in rapid succession, with each new one obliterating the rim of the one right before it.

With a bit of practice and an eye for detail, you can tell that the Rheita Valley is neither the youngest nor oldest feature in the lunar southeast. Notice a couple of battered craters on the valley's northeastern flank. Their rims and floors appear worn down because they were pounded by later impacts, proving they formed earlier. Rheita Crater in the northeast and Young D at the south end clearly came later because they look sharper and obviously reshaped the underlying valley.

The Rheita Valley is the longest and widest valley on the nearside. But many similar crater chains surround large impact features. The chains form as debris from an impact shoots out in linear sprays like the spokes on a bicycle wheel. The Rheita Valley's size implies that the impact must have been big. It was: It blasted out Mare Nectaris (Sea of Nectar) to the north.

Sunrise occurs over the Rheita Valley on January 8, but the image more closely matches what you'll see on the 9th. Take another look on the 22nd and 23rd, when the Sun sets over this region. The reversed lighting helps you see that the valley points right back to its origin in Mare Nectaris.



This wide lunar valley formed from debris blasted out by the impact that created Mare Nectaris. *CONSOLIDATED LUNAR ATLAS*/UA/LPL; INSET: NASA/GSFC/ASU

January's evening sky. The outer world lurks among the background stars of Aquarius, standing some 30° high at the end of twilight in early January. Its altitude drops by half at the end of the month, however, so don't put off your attempts to track it down.

Neptune lies midway between Lambda (λ) and Phi (ϕ) Aquarii, a pair of 4th-magnitude stars in eastern Aquarius. A trio of 5th- and 6th-magnitude stars — 81, 82, and 83 Aqr — form a right triangle in this area. But you'll need to hold your binoculars steady to spot the magnitude 7.9 planet among these stars.

Neptune lies 14' southeast of 81 Aqr on January 1. But the ice giant moves eastward and pulls away from 81. It ends the month 55' east of this star and 46' north of 83 Aqr.

A few other stars closer to Neptune's brightness populate this region, so it can be tricky to confirm a sighting. The best way is to target your suspected

— *Continued on page 42*

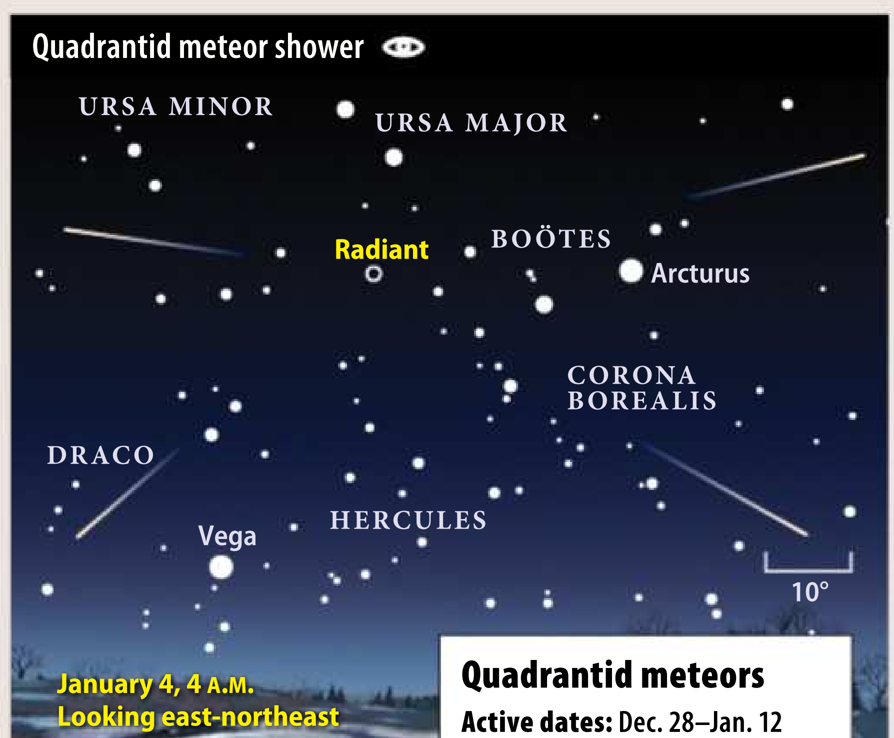
METEORWATCH

Catch the year's best meteor shower

Streaks of light should pepper the night sky when the Quadrantid meteor shower peaks the night of January 3/4. With New Moon arriving just 48 hours later, dark skies prevail all night. None of this year's other major showers fares as well. As long as the weather cooperates, observers in rural areas should see a nice show.

Scientists expect the shower to peak around 9 P.M. EST. Sadly, the radiant — the point from which the meteors appear to originate — doesn't climb high until early morning. And rates drop dramatically from the peak. The Quadrantids can produce up to 120 meteors per hour at maximum, but that number drops to 30 just eight hours on either side. Although North American observers should see a good display, the best views likely will come from Europe.

The radiant lies in northern Boötes, an area once claimed by the now-defunct constellation Quadrans Muralis. That's where the shower gets its name.



A New Moon promises dark skies for the peak of 2019's most prolific meteor shower.

Quadrantid meteors

Active dates: Dec. 28–Jan. 12
Peak: January 3
Moon at peak: New Moon
Maximum rate at peak: 120 meteors/hour

OBSERVING HIGHLIGHT The Full Moon on January 20/21 slides deeply into Earth's shadow, bringing a total lunar eclipse to observers across the Americas.

STAR DOME

How to use this map: This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

9 P.M. January 1
8 P.M. January 15
7 P.M. January 31

Planets are shown at midmonth

STAR MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

JANUARY 2019

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Calendar of events

1 The Moon passes 1.3° north of Venus, 5 P.M. EST

2 Saturn is in conjunction with the Sun, 1 A.M. EST

Earth is at perihelion (91.4 million miles from the Sun), midnight EST

3 The Moon passes 3° north of Jupiter, 3 A.M. EST

Quadrantid meteor shower peaks

5 New Moon occurs at 8:28 P.M. EST; partial solar eclipse

Venus is at greatest western elongation (47°), midnight EST

6 Uranus is stationary, 9 P.M. EST

8 The Moon is at apogee (252,850 miles from Earth), 11:29 P.M. EST

10 The Moon passes 3° south of Neptune, 5 P.M. EST

11 Pluto is in conjunction with the Sun, 7 A.M. EST

12 The Moon passes 5° south of Mars, 3 P.M. EST

14 First Quarter Moon occurs at 1:46 A.M. EST

The Moon passes 5° south of Uranus, 7 A.M. EST

15 Venus passes 8° north of Antares, 4 P.M. EST

21 Full Moon occurs at 12:16 A.M. EST; total lunar eclipse

The Moon is at perigee (222,042 miles from Earth), 3:00 P.M. EST

SPECIAL OBSERVING DATE

22 Venus passes 2° north of Jupiter before dawn.

27 Last Quarter Moon occurs at 4:10 P.M. EST

29 Mercury is in superior conjunction, 10 P.M. EST

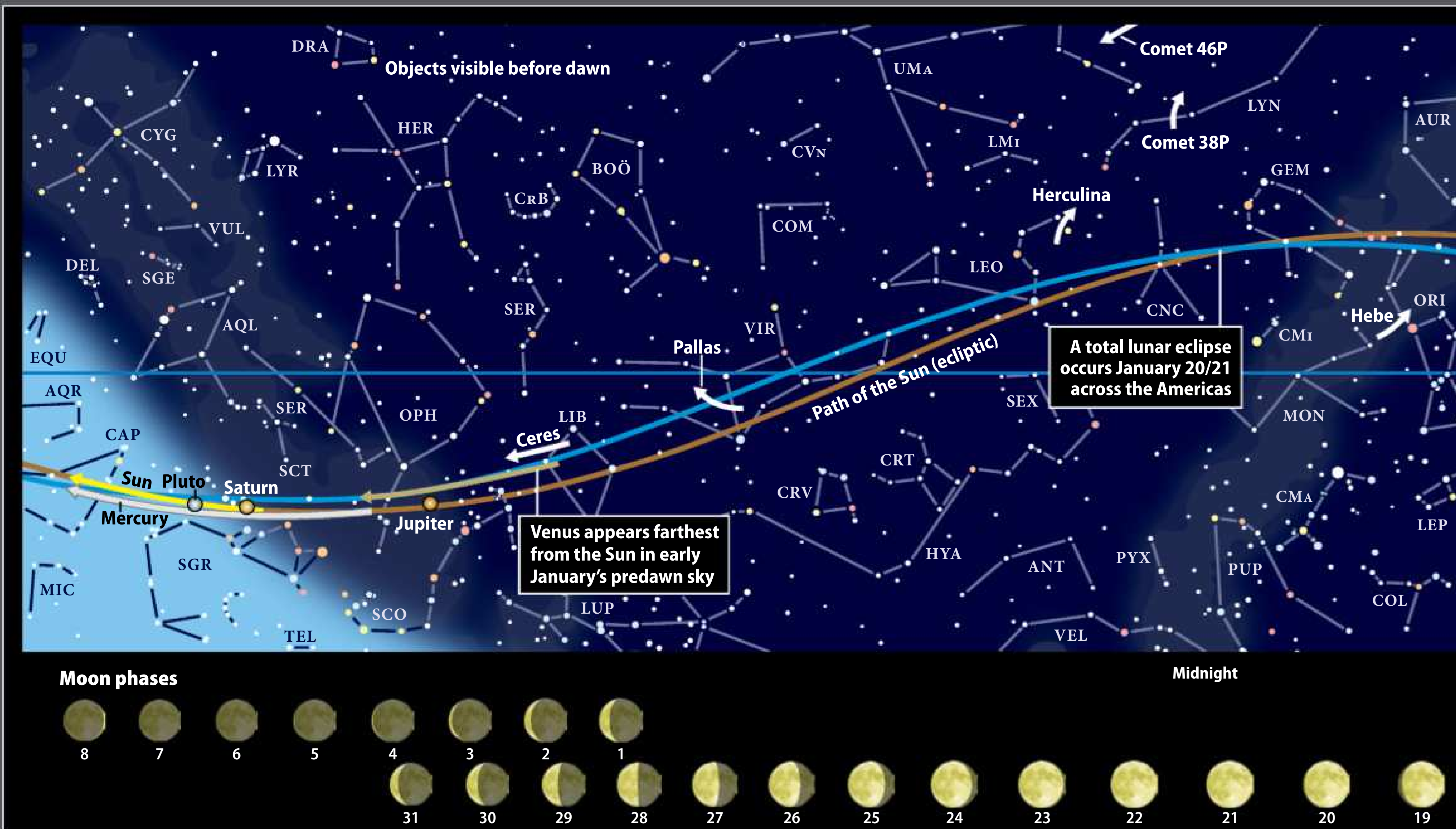
30 The Moon passes 3° north of Jupiter, 7 P.M. EST

31 The Moon passes 0.09° north of Venus, 1 P.M. EST

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**

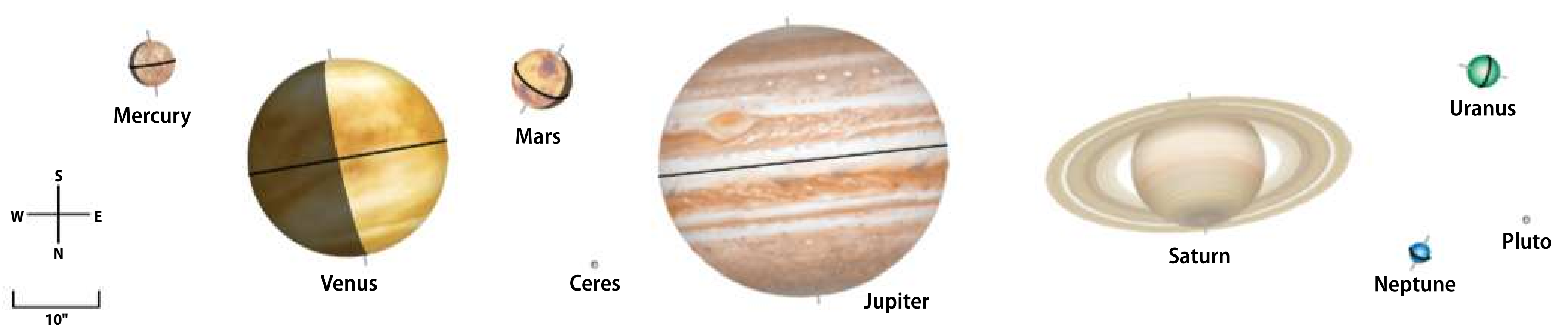
PATH OF THE PLANETS

The planets in January 2019



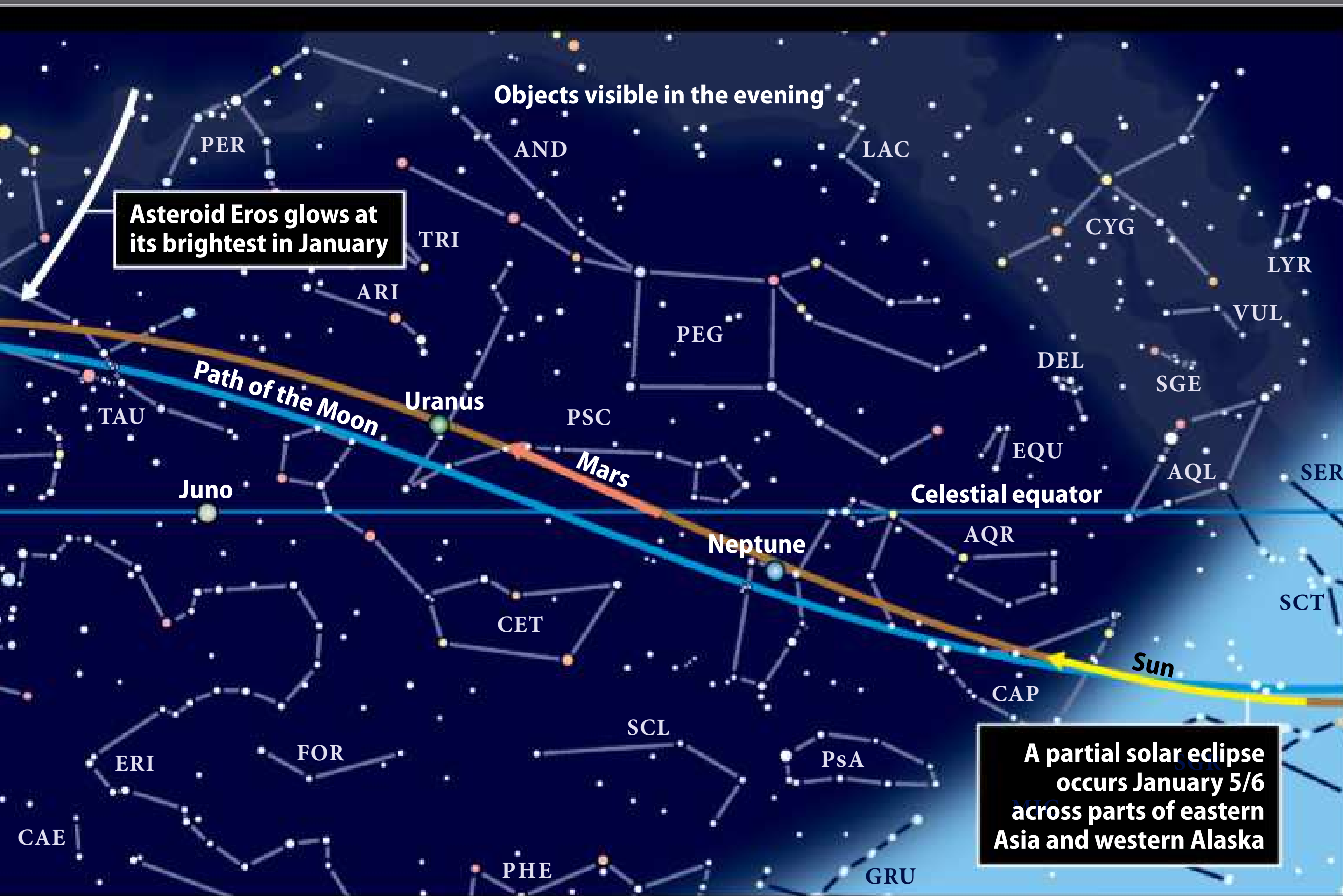
The planets in the sky

These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.



Planets	MERCURY	VENUS	MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	Jan. 1	Jan. 15	Jan. 15	Jan. 15	Jan. 15	Jan. 31	Jan. 15	Jan. 15	Jan. 15
Magnitude	–0.4	–4.5	0.7	8.9	–1.8	0.6	5.8	7.9	14.3
Angular size	5.2"	22.5"	6.8"	0.4"	32.5"	15.2"	3.6"	2.2"	0.1"
Illumination	89%	55%	88%	97%	100%	100%	100%	100%	100%
Distance (AU) from Earth	1.296	0.741	1.380	3.040	6.063	10.935	19.766	30.563	34.703
Distance (AU) from Sun	0.449	0.719	1.471	2.662	5.346	10.059	19.860	29.938	33.721
Right ascension (2000.0)	17h32.1m	16h25.7m	0h33.5m	15h40.8m	16h52.4m	19h03.1m	1h46.2m	23h03.1m	19h30.1m
Declination (2000.0)	–23°10'	–18°20'	3°37'	–13°05'	–21°54'	–22°11'	10°24'	–7°08'	–21°57'

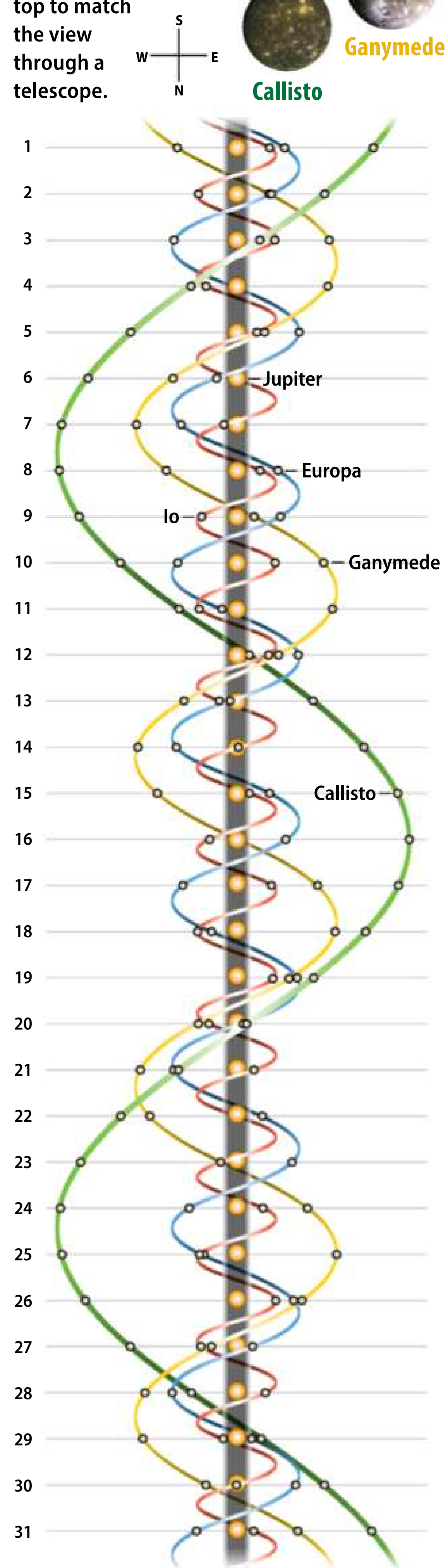
This map unfolds the entire night sky from sunset (at right) until sunrise (at left).
Arrows and colored dots show motions and locations of solar system objects during the month.



To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.
Note: Moons vary in size due to the distance from Earth and are shown at 0h Universal Time.

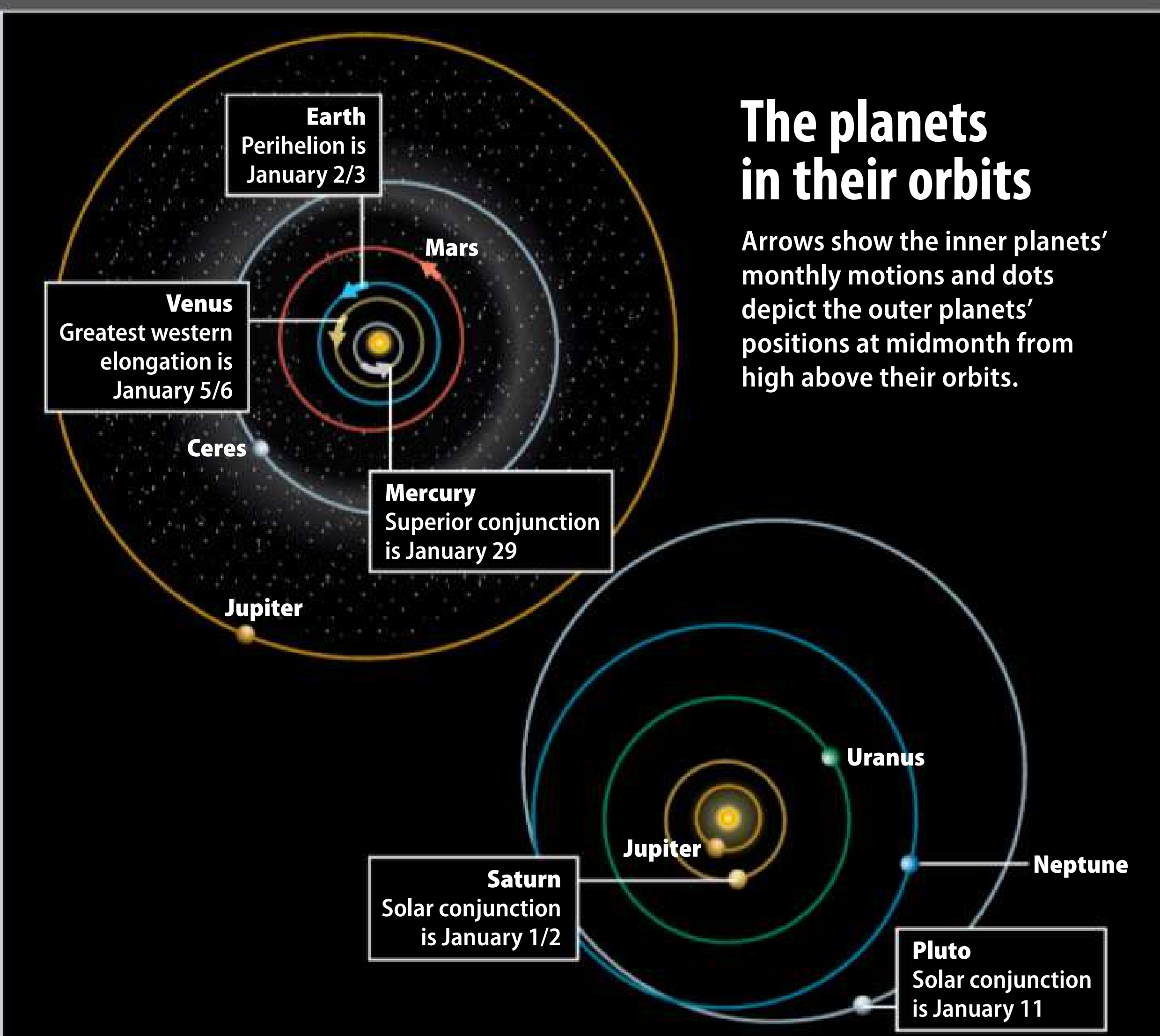
Jupiter's moons

Dots display positions of Galilean satellites at 7 A.M. EST on the date shown. South is at the top to match the view through a telescope.



The planets in their orbits

Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at midmonth from high above their orbits.



ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

— Continued from page 37

WHEN TO VIEW THE PLANETS

EVENING SKY	MIDNIGHT	MORNING SKY
Mars (southwest)	Uranus (west)	Mercury (southeast)
Uranus (south)		Venus (southeast)
Neptune (southwest)		Jupiter (southeast)
		Saturn (southeast)

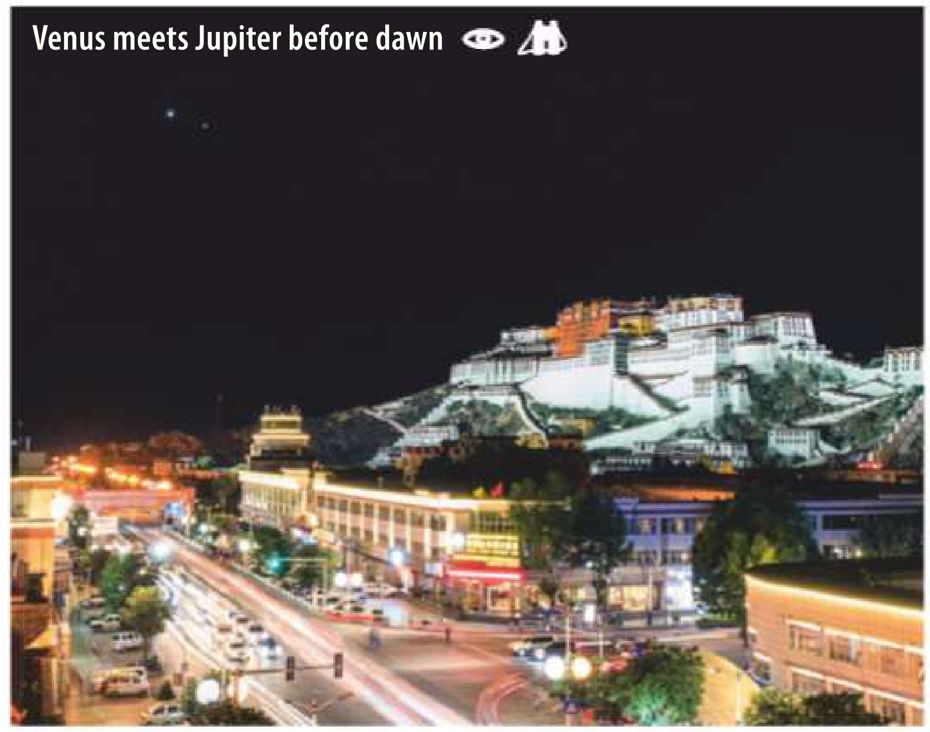
planet through a telescope. Only Neptune shows a distinct disk that spans 2.2" and displays a subtle blue-gray color.

You'll have an easier time chasing down **Uranus**. Not only does it shine brighter than Neptune (magnitude 5.8), but it also stands higher in the evening sky. Uranus spends the month in eastern Pisces, just a stone's throw from that constellation's border with Aries. The planet appears 60° above the southern horizon as twilight fades to darkness in early January, and it's still 50° high in the southwest at the same time late this month.

Uranus' position relative to the background stars barely budges during the first half of January. Look for it 1.2° north of the 4th-magnitude star Omicron (ο) Piscium. The planet edges eastward during the month's second half, reaching a point 1.4° north-northeast of Omicron by the 31st. Because no other star in the vicinity glows as brightly as Uranus, you should be able to identify it quite easily.

If you're still unsure which point of light is the planet, point a telescope in its direction. Uranus displays a disk that measures 3.6" across and appears distinctly blue-green.

Once Uranus sets after midnight, the sky remains planet-free for a few hours. But don't go to sleep yet — or at least, plan to wake up early to catch the best January has to offer.



Venus and Jupiter pass 2° from each other January 22. The two were just as close when they appeared above Tibet's Potala Palace in July 2015. JEFF DAI

New Year's Day dawns in spectacular fashion, with a waning crescent Moon and three bright planets arrayed above the southeastern horizon. The Moon rises first, just after 3 A.M. local time, with Venus following a half-hour later. Five degrees separate the night sky's two brightest objects. Jupiter comes up about 90 minutes after Venus and Mercury trails an hour later.

A half-hour before sunup, the four solar system objects stretch out across 35° of sky. Venus appears nearly 30° high and shines at magnitude –4.6; Jupiter is 15° high and glows at magnitude –1.8; and magnitude –0.4 Mercury stands 5° high in the brightening twilight. You also might catch a glimpse of the 1st-magnitude star Antares 5° to Jupiter's lower right.

COMETSEARCH

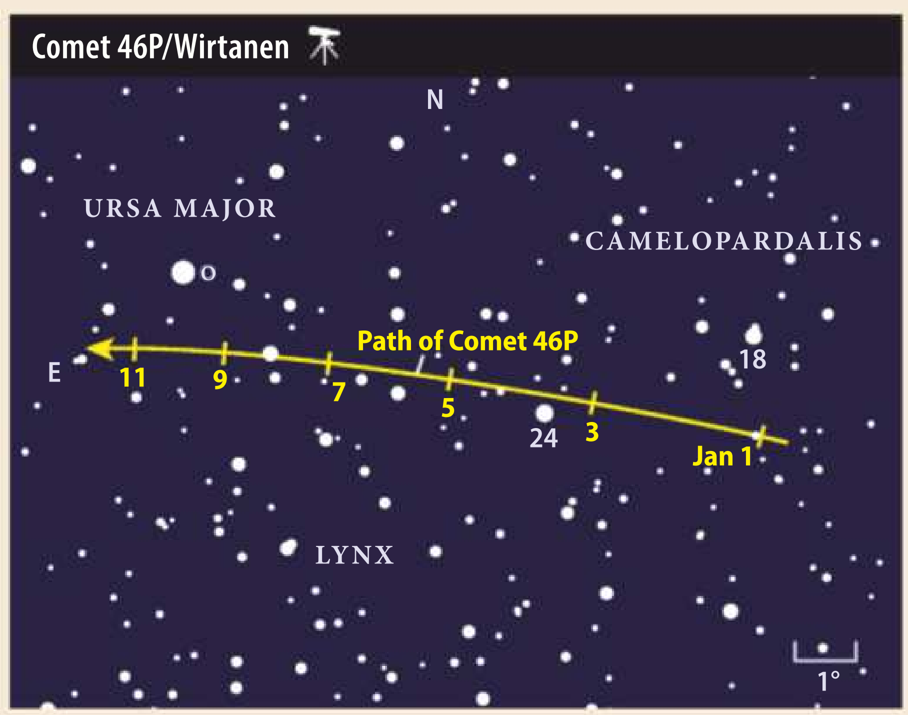
Flying right under the Bear's nose

Comet 46P/Wirtanen became the brightest periodic comet of 2018 in December, and it starts 2019 in nearly as good shape. Astronomers expect it to glow around 7th magnitude in early January as it crosses the border from northeastern Lynx into western Ursa Major. Fortunately, this region remains visible all night from mid-northern latitudes, climbing highest soon after midnight local time. Use 3rd-magnitude Omicron (ο) Ursae Majoris — the nose of the Great Bear — as your guide. Wirtanen slides 1° south of Omicron on January 10.

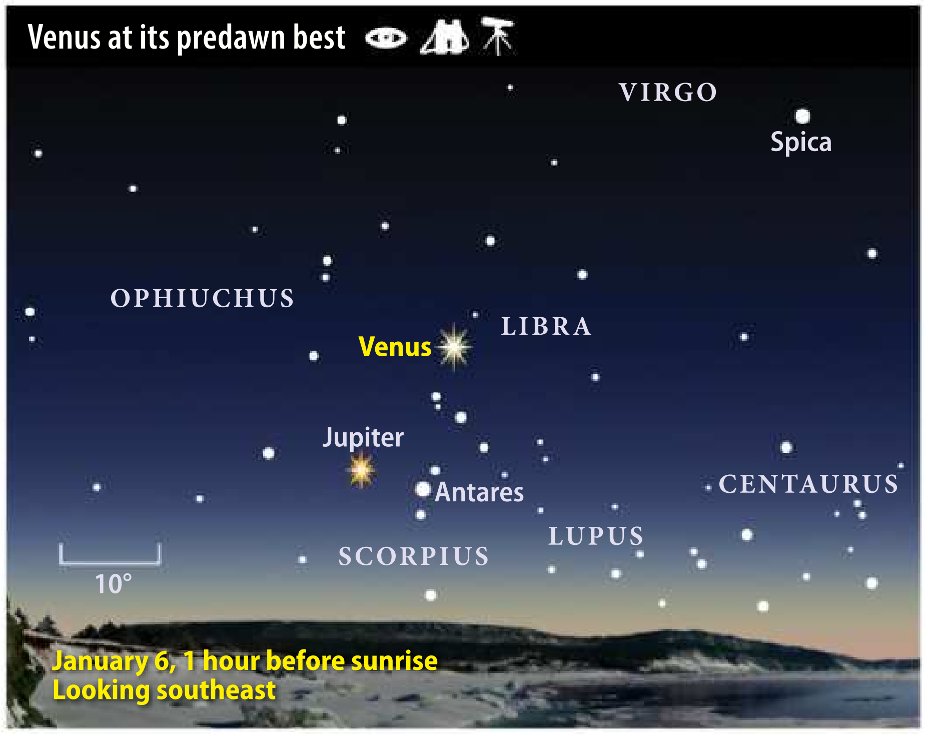
The comet made its closest approaches to both the Sun and Earth in December, and it is now leaving the inner solar system. Not surprisingly, this leads to a drop in brightness. Wirtanen may dip to 9th magnitude by month's end, so try to observe it during the Moon-free block of time in January's first 10 days.

A telescope should reveal the comet's sharp eastern flank. This is where solar radiation ionizes the gas escaping from Wirtanen, and the solar wind picks up these ions and pushes them directly away from us. Through 10-inch and larger instruments, you might see a hint of green on this edge. In contrast, the dust leaving the comet curves gently into a fan-shaped tail.

When Wirtanen returns to the inner solar system in 2024, it will be farther from Earth and likely won't make our viewing list. We'll have to wait 27 years for the comet to come close to Earth again and light up our night sky.



The brightest comet of 2018 remains a nice sight in January as it treks eastward against the background stars of Lynx and Ursa Major.



Earth's neighboring planet shines brilliantly high in the southeast when it reaches greatest elongation from the Sun during January's first week.

Over the next three days, the Moon glides past the morning planets. On the 3rd, Luna appears 4° to Jupiter's left, and the following morning, an even thinner crescent hangs 3° above Mercury.

Venus reaches greatest elongation January 5/6, when it lies 47° west of the Sun and climbs 25° high in the southeast an hour before sunrise. If you point a telescope at the planet on the 6th, you'll see a 25"-diameter disk that should appear half-lit. But it probably won't — Venus' phase always appears as a fat crescent when it should be half-lit. German astronomer Johann Schröter first described this effect in 1793, which likely arises from the planet's thick atmosphere. Observers typically see Venus as 50 percent illuminated a few days after greatest elongation. What do you find?

Each day after greatest elongation, Venus loses a bit of altitude while **Jupiter** climbs higher. The two are destined for a stunning conjunction January 22, when Venus passes 2° north of Jupiter. The pair rises in a dark sky by 4:30 A.M. local time and remains visible even in bright twilight.

A waning crescent Moon returns to the predawn sky at month's end. On January 30, it appears 6° to Jupiter's upper right; the following morning, it slides 2° to Venus' right.

Mercury has long since disappeared by then. The innermost planet adorns the twilight sky during January's first week, but the Sun's glare soon overwhelms it. It passes behind the Sun on January 29.

Although **Saturn** passes on the far side of the Sun on January 1/2, it emerges in the predawn sky during the month's second half. On the 31st, the ringed world stands 7° high in the southeast 45 minutes before sunrise. You should be able to spot the magnitude 0.6 planet through binoculars, though you'll want to wait until next month to target it with a telescope.

Observers in southwestern Alaska, Japan, and eastern Asia who practice safe solar-viewing techniques can see the Moon partially eclipse the Sun on January 5/6. Maximum eclipse occurs in eastern Siberia, where our satellite covers 71 percent of the Sun's disk.

Martin Ratcliffe *provides planetarium development for Sky-Skan, Inc., from his home in Wichita, Kansas. Meteorologist* **Alister Ling** *works for Environment Canada in Edmonton, Alberta.*

LOCATING**ASTEROIDS**

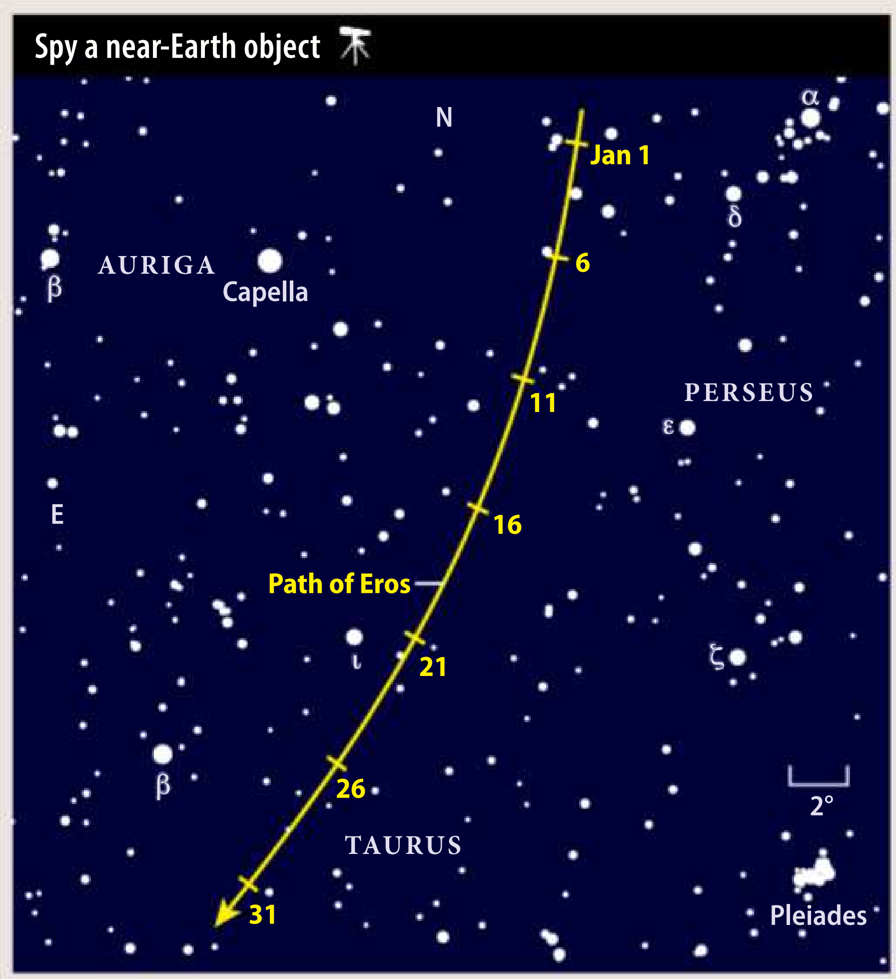
An asteroid on a deadly mission?

For an asteroid named for the Greek god of desire, 433 Eros doesn't show Earth much love. Although the orbit of this near-Earth object doesn't quite intersect our planet's path, it comes close, and astronomers suspect that gravitational perturbations will turn it into an Earth-crosser one day. In fact, there's a non-negligible chance that it will slam into our world a billion or more years from now. If it does, it won't be pretty: It would pack more punch than the asteroid that helped wipe out the dinosaurs.

For observers, Eros makes one of its periodic close passes by Earth this month. At closest approach January 15, the asteroid comes within 19 million miles of our planet. But it remains nearly this close all month, glowing at 9th magnitude from its perch high in the east after darkness falls. A small telescope will let you follow Eros as it heads south along the Perseus-Auriga border before entering Taurus near month's end. Avoid searching between January 15 and 19, when the waxing gibbous Moon spills too much light into this region.

The asteroid travels nearly 1° per day, so it takes only 30 minutes to shift position noticeably at 100x. The chart below will get you to the right field. Make a sketch of the stars in the vicinity, going deep enough to include Eros. Then, take a 30-minute break before returning to the field and noting which dot has moved the apparent width of Jupiter's disk. If you watch for half the night, you also should notice the asteroid's brightness vary by half a magnitude during its five-hour rotation.

Eros typically doesn't glow as brightly as it does this month. It won't beat 9th magnitude again until 2056, when it will peak at magnitude 7.6.



Asteroid 433 Eros swoops by Earth in January, brightening to 9th magnitude as it makes one of its rare close approaches to our planet.

GET DAILY UPDATES ON YOUR NIGHT SKY AT **www.Astronomy.com/skythisweek.**

America's observatory enters a new age

Within the dome protecting the 24-inch Clark refractor at Lowell, many historic observations were made, including Percival Lowell's viewings of Mars. INSET: LOWELL OBSERVATORY

Powered by plans laid long ago, Lowell Observatory is moving ahead with dramatic ideas for expansion and scientific greatness. **text and images by David J. Eicher**

Lowell Observatory. Mention the name to any astronomy enthusiast, and immediately visions of Pluto arise, and memories of stories about the observatory's founder, Percival Lowell, and his observations of Mars. Situated in northern Arizona at an elevation of 7,250 feet (2,210 meters), the observatory stands atop Mars Hill, which overlooks the charming town of Flagstaff below.

I like to call Lowell "America's observatory" because of its unique combination of astronomical history and famous discoveries. It's a place like no other on Earth, within or outside of science. Lowell Observatory is an independent, non-profit organization governed by a sole trustee. This gives the observatory, as well as the astronomers who work there, incredible freedom to plan and execute their own research programs.

But these days, there's a lot more going on than usual. The institution is entering a new age, one that will transform it into something well beyond what its founder might have imagined. A multimillion-dollar effort to modernize the observatory is being led by the institution's current trustee, Lowell Putnam, Percival Lowell's great-grandnephew.

A unique history

Lowell Observatory's story begins with Percival Lowell (1855–1916), part of the famous Lowell family of Boston. Percival graduated from Harvard University and MIT, and he spent his younger days running the family business based in Lowell and Lawrence, Massachusetts. Keenly interested in science from his youth, however, he was especially attracted to the mystery of Mars. In 1894, he set about establishing his childhood dream: building an observatory dedicated to studying Mars and other phenomena.

Lowell chose what would be called Mars Hill in Flagstaff after a series of site tests, and he oversaw the construction of the 24-inch Clark refractor as the observatory's primary instrument. Lowell made many observations of the Red Planet, producing drawings and famously believing that the linear features he observed — the same ones noted by Italian astronomer Giovanni Schiaparelli — could be irrigation canals built by a martian civilization. Lowell also initiated a widespread and systematic search for "Planet X," a hypothetical ninth planet believed to lie beyond the orbit of Neptune.

Starting in 1910 at Lowell, astronomer V.M. Slipher used a special spectrograph to find that many "spiral nebulae" were receding at high velocities, thus discovering the expansion of the universe. This huge cosmological find provided the initial data sets used by Edwin Hubble more than a decade later. Slipher used the same spectrograph to discover gas lurking in the Pleiades star cluster and elsewhere, thus discovering what came to be known as the interstellar medium — the stuff between the stars.

Then in 1930, a young astronomer who traveled from Kansas to work at Lowell Observatory, Clyde Tombaugh, discovered Pluto. As he compared two photographic plates made with the observatory's 13-inch telescope, he saw Pluto's image move relative to the fixed stars. Though Lowell's death preceded the discovery by 14 years, the detection of the dwarf planet permanently fixed Lowell Observatory into the American consciousness.

During the 1940s and '50s, Henry Giclas conducted a large proper motion survey that serves as a record of many years — one that is still valuable today. Indeed, the New Horizons mission used Lowell Observatory astronomer Carl Lampland's plates from 1921 to refine the course of that spacecraft. Among other discoveries made at Lowell are the co-discovery of the rings of Uranus, the detection of Pluto's atmosphere, accurate orbits for Pluto's moons Nix and Hydra, oxygen in the spectrum of Jupiter's moon Ganymede, and periodic variation in the activity of Comet Halley, just to name a few.

Members of the Lowell, Putnam, Tombaugh, Sykes, Slipher, and Christy families stand in front of the rededicated Pluto Telescope on Mars Hill during a historic gathering last June.

UNDER THE HOOD OF THE DISCOVERY CHANNEL TELESCOPE

The Discovery Channel Telescope (DCT), which saw first light in 2015, stands on a mountaintop near Happy Jack, Arizona, some 40 miles (64 kilometers) southeast of Flagstaff at an elevation of 7,740 feet (2,359 meters). Several specialized instruments are key to the current research being conducted with the scope.

One of them is the Immersion Grating Infrared Spectrometer. Developed by the University of Texas and KASI, this instrument has broad spectral reach and high spectral resolution to help astronomers study the interstellar medium, how stars form, and the early evolution of star systems.

The Extreme Precision Spectrograph is a product of Debra Fischer from Yale University. This powerful instrument has been installed at the DCT and will be used to attempt to detect Earth-like worlds around Sun-like stars.

Another specialized DCT instrument is the Rapid Infrared Imager Spectrograph, from the University of Maryland. This device will combine imaging and spectrographic capabilities so astronomers can make follow-up observations of gamma-ray bursts, as well as peer deep into star-forming regions, plus much more. — *D.J.E.*

Eyes on the stars

But at Lowell, the past is prologue, as Shakespeare said. The current expansion plans are spectacular, and they promise a very different institution a few years from now. The change is already beginning to happen, in fact. Last fall, the observatory broke ground on a new project, the Giovale Open Deck Observatory (GODO).

Named in honor of Lowell supporters Ginger and John Giovale, the complex will be built atop Mars Hill, not far from the Pluto Telescope, and it will consist of a circular observing platform and a massive building with a roll-off roof. The elevated plaza will measure almost 5,000 square feet (465 square meters) and will host multiple telescopes for public viewing, including a 32-inch Dobsonian that will be the largest telescope on the hill. The GODO will be unique in the world of public observing. It is planned to open for visitors this spring.

Thanks to a steadily growing base of more than 100,000 visitors each year, Lowell is undertaking an ambitious fundraising effort to help achieve a whole set of new goals that will bring the observatory into a new era. Among many other upgrades, the plans

MEET THE RESEARCHERS AT LOWELL

Deputy Director for Science **Michael West** is a longtime galaxy expert whose research interests include star clusters, galaxy formation and evolution, clusters of galaxies, and the large-scale structure of the cosmos. He is also very active in astronomy education and outreach, as well as promotion of dark skies.

Astronomer **George Jacoby**, former deputy director for technology, is an expert on planetary nebulae who spent most of his career at the National Optical Astronomy Observatory in Tucson. Jacoby, who retired last fall, also conducted a great deal of research at Kitt Peak National Observatory, where he served as director of WIYN Observatory.

Ted Dunham, who also retired last fall, was responsible for astronomical instrumentation developed at Lowell Observatory. His research centered on stellar occultations by planets in the solar system, using observations made aboard the airborne observatory SOFIA.

Focusing on icy outer solar system objects, **Will Grundy** uses a variety of techniques to discover and determine the orbits and masses of binary Kuiper Belt objects. He is the surface composition team lead for the New Horizons mission to Pluto and beyond, and an editor of the planetary science journal *Icarus*.

Jennifer Hanley is interested in the stability of liquids throughout the solar system, with particular focus on Mars, Titan, and Europa. By studying the properties of liquids at low temperatures and pressures, Hanley hopes her work sheds light on the worlds of Pluto and Titan. She also researches the stability of water and associated chlorine salts on Mars and Europa.

A longtime expert on galaxies, **Deidre Hunter** focuses on star-forming properties of dwarf galaxies, and all aspects of tiny, irregular galaxies, the most plentiful type in the universe. Hunter is an award-winning leader of Lowell's innovative program to teach science and astronomy to Navajo and Hopi classrooms around Flagstaff.

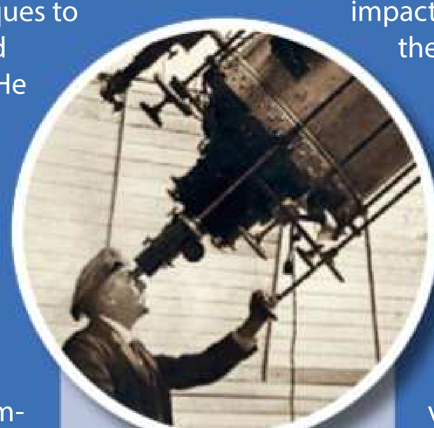
As Discovery Channel Telescope scientist, **Stephen Levine** was vital in bringing Lowell's modern instrument from concept to full-time science operations during its commissioning phase. Levine's primary research interests include large astrometric surveys and numerical simulations of astrophysical disk systems, with a particular focus on the evolution of lopsided disks and irregular galaxies.

Joe Llama focuses on solar systems throughout the Milky Way Galaxy, investigating their potential for habitable planets. He is also actively involved in searching for exoplanetary magnetic fields and understanding how they may shield a planet from overpowering radiation.

Phil Massey is the principal investigator for the Large Monolithic Imager, the primary optical camera on the Discovery Channel Telescope. He is interested in studying massive stars, binary stars, young star clusters, and the young stars in nearby galaxies to understand how the most luminous stars evolve.

Focusing on the solar system, **Michael Mommert** is chiefly absorbed with studying the physical properties of asteroids and comets. He observes these objects in wavelengths ranging from optical to near-infrared to help unravel their compositions, masses, reflectivities, rotational properties, and overall shapes.

Also highly interested in small solar system objects is **Nick Moskovitz**, who studies asteroids using observations and modeling. His work focuses on collecting data to understand the link between asteroids and meteorites, the origins of asteroid impactors, and the geologic processes in the early history of the solar system.



Percival Lowell observes with the Clark refractor at Lowell Observatory in 1914. LOWELL OBSERVATORY

Lisa Prato is a stellar and planetary astronomer who focuses on three specialized areas: measuring accurate mass ratios in binary star systems within young star-forming regions, studying the properties of stars and their planet-forming disks in binary systems, and surveying radial velocities for the youngest planets forming around low-mass stars.

A veteran of Lowell's staff, **Dave Schleicher** is an expert on comets — specifically their physical properties, chemical compositions, and evolutionary behaviors. A co-discoverer of periodic variability of Comet Halley, Schleicher uses both observation and theoretical modeling to push forward our understanding of these icy bodies.

Gerard van Belle, director of the Navy Precision Optical Interferometer, is an expert on the fundamental properties of stars — their masses, sizes, and temperatures. He is interested in understanding the internal structures and evolution of stars so that astronomers can understand the numerous planets being discovered orbiting nearby stars.

Larry Wasserman, also a veteran of Lowell's staff, studies solar system bodies using occultations. His predictions, observations, and resulting data from these events have produced a huge amount of knowledge of the properties of solar system bodies. — *D.J.E.*

include a huge new building called the Astronomy Discovery Center. It will house numerous displays and exhibits, contain a theater that can host astronomical lectures and state-of-the-art shows, and feature the Dark Sky Planetarium, where crowds can gaze up at the night sky while presenters point out visible features and constellations.

The 4-meter telescope

Where did this incredible expansion and sense of drive come from? A generation ago, Lowell's astronomers and trustee had big ideas. Though the institution is deeply steeped in history, they realized they needed a modern large telescope. In 2003, former Discovery CEO and founder John Hendricks proposed what would become a $16 million gift to commence the 4.3-meter Discovery Channel Telescope (DCT), the largest and most sophisticated telescope in northern Arizona.

The DCT completely reworked Lowell and sent the organization into a more modern, more complex era of operations, one that depends on a committed staff of around 120 employees and many hardworking volunteers. The DCT saw first light in 2015 and has been a workhorse ever since.

The DCT is by no means all of Lowell's science activities. Some 12 miles (19 kilometers) southwest of Flagstaff stands Anderson Mesa, a shelf that has supported multiple telescopes from both Lowell Observatory and the U.S. Naval Observatory since the 1950s.

But the big news at Anderson Mesa in recent times has come from a different angle. Construction began in 1992 on a telescope that is so modern, it challenges technology and data interpretation. The Navy Precision Optical Interferometer (NPOI) is a joint effort of Lowell, the U.S. Naval Observatory, and the Naval Research Laboratory.

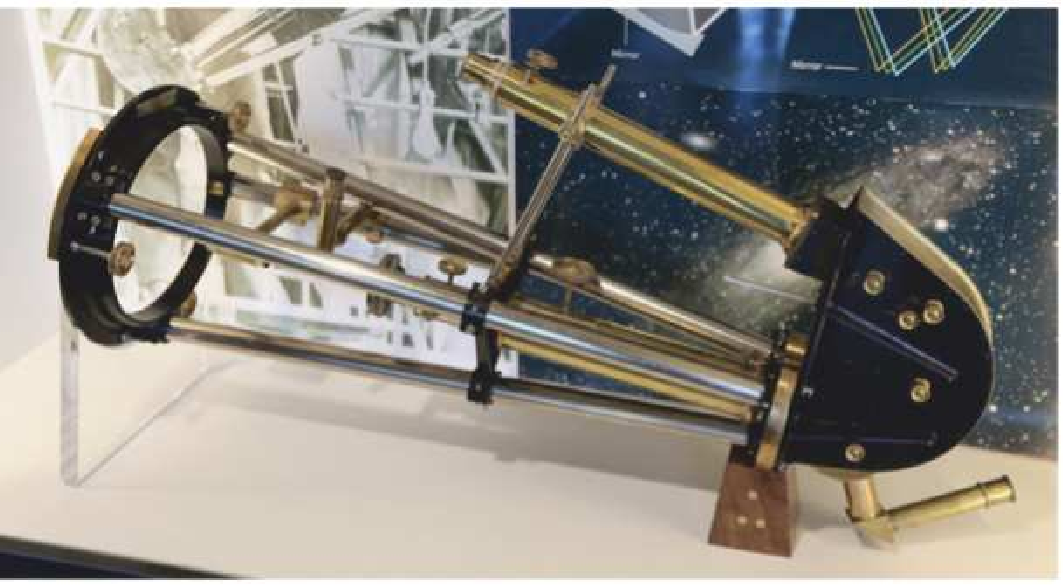
This specialized telescope can take measurements of the universe in high-precision ways. NPOI uses an array of up to six mirrors laid out in a Y-shaped configuration, bringing the beams of light together to create ultra-high-resolution images. Because of the technique, NPOI can produce images of close binary stars that only appear as a single point of light in even the largest conventional telescopes, measure the diameter of supergiant stars, and record the positions of stars in the sky so accurately that the Naval Observatory uses it as a standard for timekeeping.

With such great history and an amazing array of instruments, Lowell has become an extremely active center of

RIGHT: The refurbished and rededicated Pluto Telescope gleams in its dome in June 2018.

RIGHT: Clyde Tombaugh's son and daughter, Alden and Annette Tombaugh, stand next to the Pluto Telescope, with which their father discovered Pluto in 1930.

BELOW: In Lowell's Collection Center, you can see the Slipher Spectrograph, with which V.M. Slipher discovered the expansion of the universe and the existence of the interstellar medium.



ABOVE: Atop Mars Hill, Jim Christy poses with fellow astronomers and his wife, Charlene, commemorating the 40th anniversary of his discovery of Charon, Pluto's largest moon. Pictured from left are Paul Shankland, director of the U.S. Naval Observatory; Jim Christy; Jeff Hall, director of Lowell Observatory; Lowell Observatory trustee Lowell Putnam; and Charlene Christy, for whom Charon was named.

LEFT: Percival Lowell's first telescope, which was given to him when he was a boy.

astronomical research. The coordinated effort at Lowell begins with the facility's energetic, expert, and affable director, Jeff Hall. The director since 2010, Hall is an astronomer and dark-sky activist with considerable expertise in solar and stellar science. He and several colleagues run a program monitoring solar and stellar activity cycles aimed at better understanding the full range of variations that Sun-like stars exhibit, lending a more complete view to the possible influence of the Sun on Earth's climate.

The future starts now

In June, I was privileged to be at Lowell once again, attending the annual meeting of the observatory's board of advisers, asked to join this group by Lowell Putnam. Having been to just two of these meetings, I can't tell you how exciting the future looks for Lowell. Discussing the huge plans for expansion and science outreach with Putnam, Jeff Hall, Michael West, and others, really crystallizes a vision for the place.

The Lowell gathering was magical, as we celebrated the rededication of the Pluto Telescope with members of astronomy's royal families attached to the observatory: Lowells, Putnams, Sykes, Tombaughs, Sliphers, and Christys were there for the ceremony. (In 1978, across town at the U.S. Naval Observatory, Jim Christy discovered Pluto's moon Charon, named for his wife Charlene; both Jim and Charlene were on hand 40 years after the discovery, to help with the celebration.) Thanks to the graciousness of the observatory staff, I was able to stay in the apartment in which Clyde Tombaugh lived when he discovered Pluto in 1930. The sense of history there was palpable: I could almost hear Clyde delivering his many rapid-fire puns once again.

The future of Lowell began this past fall with the groundbreaking of the GODO. An ambitious program — with an expanded visitor center, museum spaces, logistics for handling larger crowds on Mars Hill, dark-sky planetarium, and much more — will follow. It strains the imagination that Percival Lowell could have imagined the explosive growth and science leadership that seems destined for this institution. America's observatory is about to take on an entirely new role, and it will be an exciting ride to watch unfold.

David J. Eicher *is the editor of* Astronomy *and a member of the Board of Advisors of Lowell Observatory.*

Check out an extended version of this story at www.astronomy.com/magazine/news/2018/10/lowell-observatory. For more information on Lowell, visit www.lowell.edu.

A deep-sky *winter wonderland*

Three areas of winter sky hold surprises for hunters of clusters, nebulae, and galaxies.

by Stephen James O'Meara

Visible to the naked eye, the North America Nebula (NGC 7000) is a vast region of star formation in Cygnus. ADAM BLOCK/NOAO/AURA/NSF

Sometimes called the Pink Pillow Nebula, planetary NGC 7027 is famous for its boxy appearance. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

NGC 7044, sometimes called the Starfish Cluster, is a dim grouping of several dozen stars, making it an interesting challenge in small scopes. MARTIN C. GERMANO

Get ready to explore some celestial wonderlands. I've selected three regions of sky, all 3° across and roughly centered on a naked-eye star. While many such regions in the sky exist, these three in particular harbor an eclectic mix of disparate targets. Some are bright, some are dim, and some are just right — they're beautiful objects no matter what size telescope you use. All lie in visually soft beds of the rich Milky Way.

Astroimagers may find some of the objects of particular interest because they are immersed in a rich wonderland of deep-sky objects normally beyond the limits of the eye. So enjoy the hunt — and the views.

Swan lake

Our first stop is a milky lake of celestial wonders east of Deneb in Cygnus the Swan. The **North America Nebula** (NGC 7000) is a wonderland unto itself. It lies only 1° west of 4th-magnitude Xi (ξ) Cygni and forms part of a large HII region some 2,000 light-years distant. Under a dark sky, unaided eyes can readily pull out the boxy glow representing Canada and the central United States, but you'll need binoculars to see the entire continental outline. Through a telescope, use low power to see its countless suns scattered across a pale green glow, looking like scintillating gems emerging from a sheet of melting ice.

Return to Xi Cygni and move about 1¾° south to find the magnitude 8.5 planetary nebula **NGC 7027**, sometimes called the Pink Pillow. It's one of my favorites. Although it's visible in binoculars, the nebula requires considerable magnification (consider 100x per inch of aperture) to see details in its tiny 18" disk. Don't be shy, as this

A beautiful but faint planetary nebula, NGC 7048 shows off a ringlike shape that will dazzle users of medium and large scopes. RICHARD ROBINSON/BEVERLY ERDMAN/ADAM BLOCK/NOAO/AURA/NSF

Lodged in an asterism of bright stars, the open cluster NGC 7039 offers a rich melange of faint stars in a neat pattern. ANTHONY AYIOMAMITIS

Bright and impressive in any telescope, open cluster M52 is a winter sky showpiece. ANTHONY AYIOMAMITIS

is one of the densest, and therefore youngest, planetary nebulae known. Look for a dumbbell-shaped glow oriented north-northwest to south-southeast, with the north-northwest side being the brightest; that section also contains a bright knot centered on the nebula's northwestern edge. Large-telescope owners should look for the bright lobe displaying beautifully contrasting pink and green hues.

A sweep about 1° east-northeast will take you to the challenging **Starfish Cluster** (NGC 7044). Glowing dimly at 11th magnitude, this 5'-wide splash of phantom starlight is a threshold object in a 4-inch scope under dark skies. It's difficult to resolve even in moderate apertures, with just a few members flitting in and out of view with averted vision at high power. The brightest stars form a central cross. The starfish moniker comes from its appearance in photographs. But it's a worthy visual challenge nonetheless.

Return to Xi Cygni once again. This time, use your binoculars to sweep about 2° to the northeast, where you'll find the magnitude 7.5 open cluster **NGC 7039**. This 15'-wide cluster lies about 3,000 light-years distant, and it is nestled in a 40'-wide butterfly asterism of about a half-dozen 7th- to 8th-magnitude stars oriented east–west. The young cluster is best appreciated in low-power telescopes, as its 100 or so members effervesce into the rich Milky Way background quite easily.

A gentle push 45' northeast of the 7th-magnitude central star at the heart of NGC 7039 will bring you to planetary nebula **NGC 7048**. At 12th magnitude, this planetary should be a challenge to small-telescope users without a go-to mount, as it requires a dark sky, good star-hopping skills, and some patience. In images, the nebula displays a somewhat ragged but generally ringlike appearance with a diffuse halo extending roughly perpendicular to the ring's major axis. Through a 5-inch scope, magnifications greater than 100x reveal only an amorphous circular glow of mostly uniform light with averted vision.

Slipping about 3° north-northwest, we come to the magnitude 4.5 star 63 Cygni, only 12' north-northwest of which is another marvelously minute planetary nebula, the **Cheeseburger Nebula** (NGC 7026). Glowing at 11th magnitude, this 21"-diameter disk has a central ring structure with bipolar lobes on each side, giving it an amorphous butterfly appearance. Through a 5-inch telescope, I've used 180x to glimpse this shape, which is oriented roughly north–south. To see the cheeseburger (opposing enhancements along the ring) requires magnifications between 75x and 100x per inch of aperture. Again, the nebula is small and tight, so it takes power well.

A beautiful dark nebula, **Barnard 361**, lies about 1° east of 63 Cygni. Through a 5-inch scope, this 30'-wide stain in the Milky Way is rimmed by

The large dark nebula Barnard 361 (bottom center) looks like a hole in space when viewed with a low-power scope. Above the dark nebula lies the small open star cluster IC 1369. BERNHARD HUBL

To spot the famous Bubble Nebula (NGC 7635), visual observers will need dark skies and a large backyard scope. BRAD EHRHORN/ADAM BLOCK/NOAO/AURA/NSF

folds of scintillating starlight. Here you'll find 12th-magnitude open star cluster **IC 1369** — a whisper of dim starlight packed within only 5' of sky about 30' beyond the dark cloud's northern edge, arranged like an afterthought.

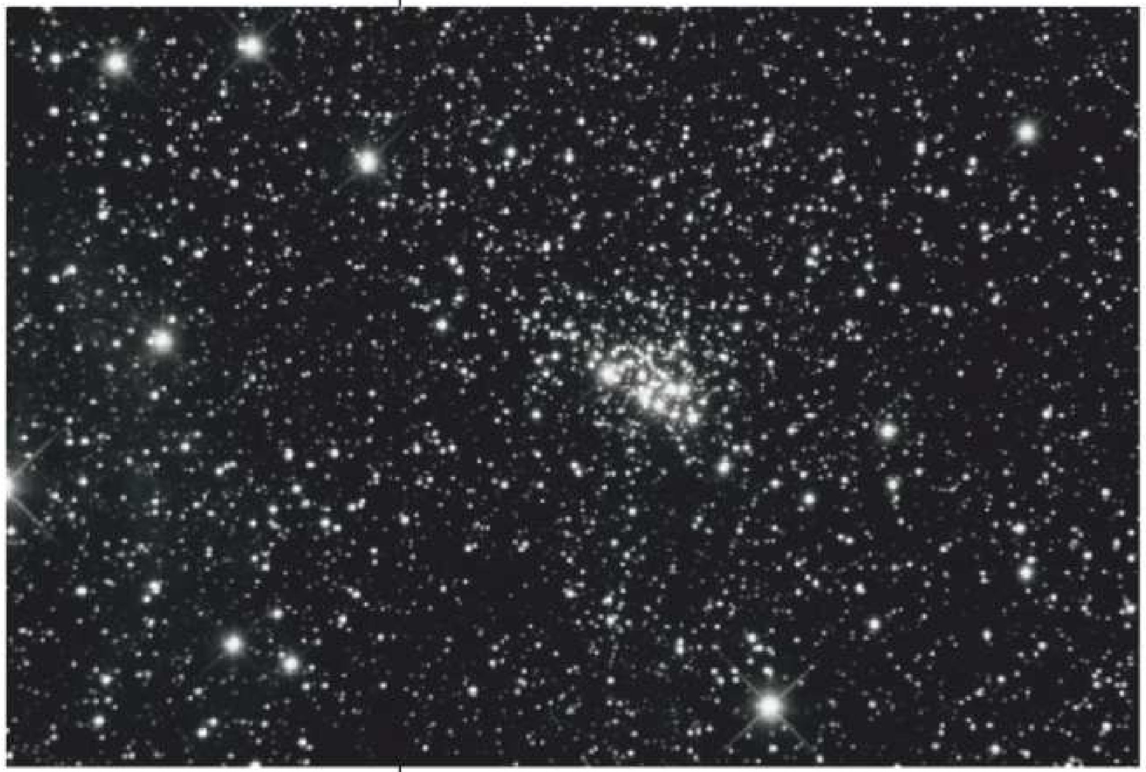
Royal riches

An outpouring of deep-sky riches lies south and west from 5th-magnitude 4 Cassiopeiae. We'll start at a visual wallopalooza: open cluster **M52**, a metaphorical "purple haze" of about 200 young suns ½° south of the star. Through 10x50 binoculars, the 60 million-year old cluster looks like a double star caught in a haze. Telescopically, it is a disco ball of tiny blue crystal chips, while thin wisps of faint stars jut from the globe like dust in a sunbeam.

Only 35' to the southwest is the dauntingly dim object called the **Bubble Nebula** (NGC 7635), an even fainter ring of gas, whose brightest section abuts a 9th-magnitude star. While this object measures 15' by 8', the bubble spans only 3' across. Through a 4-inch telescope, it is only weakly visible under dark skies. Although the Bubble resembles a planetary nebula, it is part of an HII region wherein ferocious winds from the 9th-magnitude star have sculpted the surrounding gas and dust into the shape we see today.

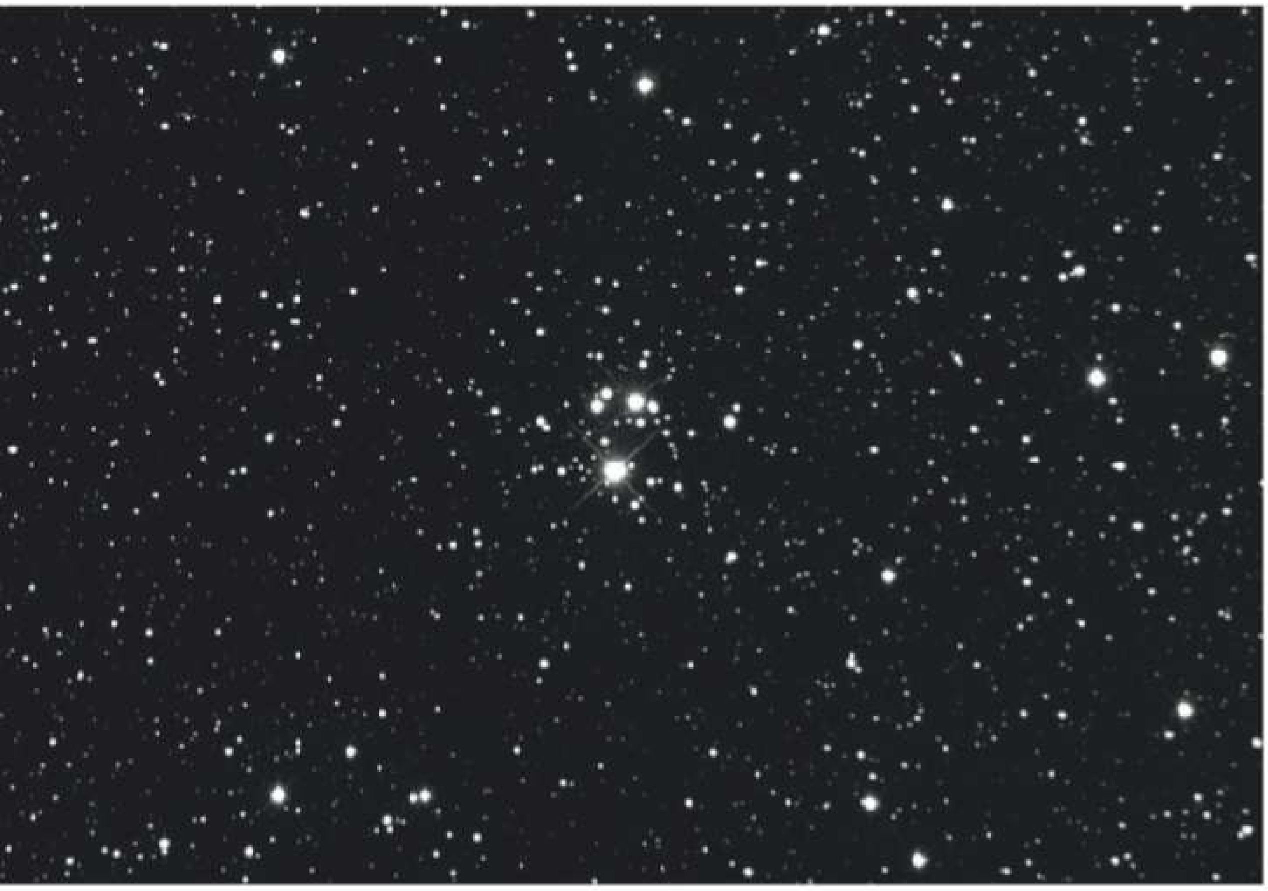
Less than 1° west-northwest of the Bubble Nebula, we find a miniature delight called the **Little Lagoon Nebula** (NGC 7538). This 9'-by-6' emission nebula lies 9,000 light-years distant in the Cassiopeia OB2 association, which is rich in HII regions, dark clouds, young clusters, and reflection nebulae, so it is a gem for wide-field astroimagers. Telescopically, the lagoon appearance is lost, appearing only as a diffuse glow around two central stars with a knot of nebulosity to the southwest — but that's where active star formation is occurring.

Less than 1° south-southwest of the Little Lagoon is the delightful **Dormouse Cluster** (NGC 7510). Although the cluster is relatively dim (magnitude 8) and small (7'), it features a prominent spearhead of stars within a longer squashed ellipse of slightly brighter suns. Use high power to enjoy this



Open cluster NGC 7510 has a distinctive wedge shape that will stand out in virtually any telescope.
MARTIN C. GERMANO

The unusual emission nebula IC 1470 is a tiny, 11th-magnitude glow that will challenge observers to catch it under a dark sky.
JAMES R. FOSTER



The poor open cluster NGC 2129 appears like a knot of stars surrounding two bright suns in an otherwise barren field.
MARTIN C. GERMANO

little gem, which contains about two dozen stars ranging in brightness from magnitude 10 to 13.

Continuing to the southwest, sweep less than 1° beyond the Dormouse to the challenging and highly neglected emission nebula **IC 1470**. This tiny (3') glow shines dimly at 11th magnitude (the brightness of its illuminating star). Moderately large apertures and magnifications in the 250x range are required to pick out this piece of celestial lint. Look for a moist exhalation of gossamer light clinging to the star like a phantom dust bunny. In images, this nebula is also reminiscent of the Lagoon Nebula (M8). So we have two mini-lagoons within 1° of one another.

Castor's toe ring

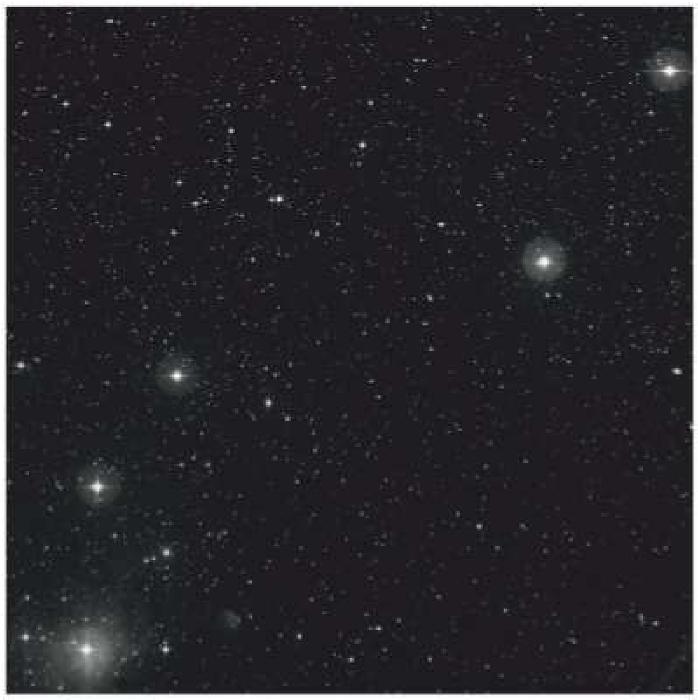
Within 3° of 3rd-magnitude Eta (η) Geminorum, we find six open star clusters, two nebulae, and one challenging supernova remnant. We'll move counterclockwise from what I call the Peek-a-Boo cluster: **Collinder 89**.

Ever see this open cluster? Many do without even knowing. It forms an ellipse around the chain of stars between 9 and 12 Gem, about 1½° northwest of Mu (μ) Gem, one of Castor the Twin's toes. The cluster shines around 6th magnitude and contains 20 stars within a 1° circle — so, yes, it is huge! Use binoculars or low power (about 20x) in a telescope to see this large and loose elliptical cluster. Look for delicate spirals of stars lifting off the loose and scattered core, especially at the two ends. Relax your gaze to take it all in.

Don't move a muscle because our next target is literally in the same field of view: reflection nebula **IC 444**. This haunting 30' spirit of air veils 12 Gem (its illuminating star) and is one of those objects that confounds, as some have spied it in large binoculars, while others using moderate apertures have had difficulty. It's reminiscent of nebulosity in the Pleiades (M45) — so think delicate and diffuse. Also be aware that visual observers will most likely detect only the brightest 10' of it. The rest is best left for astroimagers.

Now loop over to four clusters between 1 Gem and 5 Gem (and slightly beyond). First up is the highly neglected open cluster **NGC 2129**. You'll find this small (6') open cluster less than 45' west and slightly north of 1 Gem. Use 70x and higher to look for about a dozen suns coarsely scattered around a central triangle of 8th-magnitude stars. Larger scopes will triple the number of stars in that tiny area!

Hop over to 5 Gem and use your eyes or binoculars to spy **M35**, a 5th-magnitude open star cluster and one of the richest, most compact, and nearby open clusters. Some 200 stars or more are splashed across a 30' field; its brightest members form a figure-eight pattern or corset of about two dozen suns that seem to hold in the cluster's slender waist.



Sharing the same low-power view with M35 is the 8th-magnitude, pint-sized (5') open cluster **NGC 2158**, just ½° southwest of M35. Now for the fun part: Although NGC 2158 appears smaller and dimmer than M35, the two clusters are really similar in physical size; it's just that NGC 2158 is six times more distant.

Magnitude 8.5 open cluster **IC 2157**, a near cousin to NGC 2158 in magnitude and size but not in the number of stars — which is only 20 — lies about ½° west-southwest of NGC 2158. Little wonder it is so overlooked.

Let's drop southward to 5th-magnitude 68 Orionis, where, about 1° to the north-northwest we encounter **NGC 2175**, sometimes called the Monkey Head Nebula. This is one of my favorite hidden treasures of the night sky. This 40'-by-30' swath of gossamer light in an extremely rich field of Milky Way includes the possible open cluster Collinder 84. A delight to see under a dark sky, it is visible in 7x50 binoculars; telescopically, especially at low power, it appears as a vast, irregularly round glow of pale uniform light with an illuminating magnitude 7.6 star at the center. Inside the larger nebula, on the northern side, an extremely faint wisp of nebulosity between three stars has its own NGC number: **NGC 2174**.

Before we close our tour with a bang, let's return to our starting star: **Eta Geminorum**, a magnificent tight double made up of a magnitude 3.5 M-class giant with a blue 6th-magnitude companion 1.7" distant. Once you've finished appreciating this highly neglected pair, get ready for what I would consider an ultimate challenge for moderate-sized and larger telescopes: supernova remnant **IC 443**, sometimes called the Jellyfish Nebula.

I have long looked for this challenging object with minimal success. I've definitely seen only the brighter northeastern component, with extreme difficulty, once through my 5-inch scope at 30x under the dark skies of Volcano, Hawaii, and once more dramatically through amateur astronomer Mario Motta's 32-inch reflector in Gloucester, Massachusetts. This segment — a 10'-by-5' comma of fantastically faint light (oriented northwest-southeast) 50' northeast of Eta — represents one edge where the supernova's expanding shock wave collided with a dense molecular cloud some 5,000 years ago. Use an Oxygen-III filter to help bring it out. The fainter tendrils of the jellyfish abut Eta to the northeast and lie in the same field, forming perpendicular ripples of light that best show in astrophotos. Indeed, wide-field astrophotos can capture the entire Jellyfish, reflection nebula IC 444, and open cluster Collinder 89 in a single field.

As you explore the winter sky, take time to note these amazing regions where unusual and myriad deep-sky objects cluster together. They just might give you a new appreciation for hunting deep-sky objects in the cold of the night.

Stephen James O'Meara *is a contributing editor of* Astronomy *and the author of numerous books on astronomical observing.*

←← Collinder 89 is a large, sparse open cluster that forms an ellipse and holds 20 stars over an area of 1°. DIGITIZED SKY SURVEY

↑ IC 443, sometimes called the Jellyfish Nebula, is one of the sky's finer examples of a supernova remnant. To target it, you'll need a large backyard telescope. BOB FERA

↓ One of the winter sky's great open clusters, M35 is a bright, sprawling load of suns (left), and it lies close to the more distant open cluster NGC 2158 (right). NEIL FLEMING

TEST YOUR under the

No matter what type of telescope you use, or how big it is, at some point you need to test its optics. PHIL JONES

TELESCOPE stars

Equipment guru **Tom Trusock** *discusses simple methods to check and diagnose optical issues.*

FINALLY! THE TELESCOPE YOU'VE WANTED HAS ARRIVED! Maybe it's your first; maybe it's your fourth. Maybe, like some of us, it's your 23rd. A clear night comes, you set it up under the stars, and … things don't look quite right. Where do you go from here?

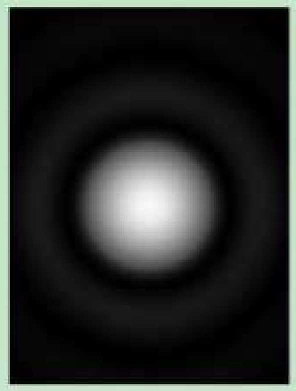
To get you through this trauma, I've created a simple, easy-to-follow procedure to evaluate your optics. It requires you, your telescope, and a night of good seeing (atmospheric steadiness).

Testing a telescope under the stars is a critical examination. Nearly all telescopes have some peculiarity. A noted optical designer once told me, "You pick what aberrations you want to correct for and what you can live with." So remember, nothing's perfect. Don't judge too harshly. I've never seen perfect optics; that said, most of the issues I have seen have been either easy to correct (collimation, tube currents, retaining ring too tight, not enough cool-down time) or really don't affect the view much.

If you're looking for a more in-depth approach, you can find numerous books and web articles on this topic. There are also software programs that help you identify exactly what you're looking at in the defocused patterns, artificial stars that allow you to test your scope during the day, and products that make testing even easier, like Ronchi gratings. As a last resort, you can have the optics checked professionally.

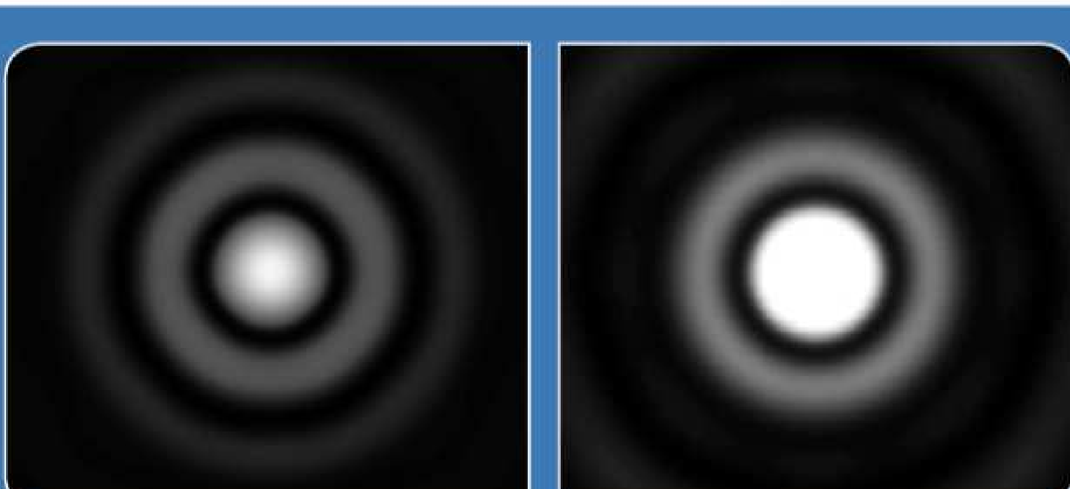
Before you test

First, check your seeing. The atmosphere must be calm to perform a valid test. In my home state of Michigan, it's rare to get conditions that are steady enough to test any scope with an aperture over 8 inches. Here's a tip: If the stars are twinkling wildly, don't bother testing your telescope that night.



This image shows a perfect Airy disk. Almost all the light forms the central disk, with little left to create the diffraction ring. IMAGE GENERATED BY ABERRATOR (COR BERREVOETS)

Coma results in star images looking like comets; this image shows a severe case. The effect gets more pronounced as the object gets closer to the edge of the field of view. IMAGE GENERATED BY ABERRATOR (COR BERREVOETS)



These images show higher-order (left) and lower-order (right) spherical aberration (SA). When only part of the surface (like an edge) is bad, the defect is higher-order SA. Lower-order SA means the entire surface is at fault, like when a mirror is ground too shallow or too deep. IMAGES GENERATED BY ABERRATOR (COR BERREVOETS)

Next, allow enough time for your telescope to cool down. At least an hour, maybe longer depending on the temperature change you're putting it through. If you can, store your scope somewhere where the temperature will be the same as outside. If the temperature keeps dropping through the night, your optics never will stabilize. And when that happens, you'll see a laundry list of issues.

Third, choose your testing eyepiece. You'll want either a simple design like a Plössl or something well corrected, like a modern wide-field design. Choose an eyepiece that provides moderate to high power, typically one that magnifies 40 to 60 times per inch of aperture. For example, if you are using a 4-inch scope, pick an eyepiece that magnifies between 160 and 240 times. Alternatively, choose one that matches the focal ratio of your telescope. So, for an f/5 scope, pick a 5mm eyepiece.

Fourth, be sure your telescope is collimated. If the scope's optics are out of alignment, you're not getting the best performance. This makes any sort of test pointless.

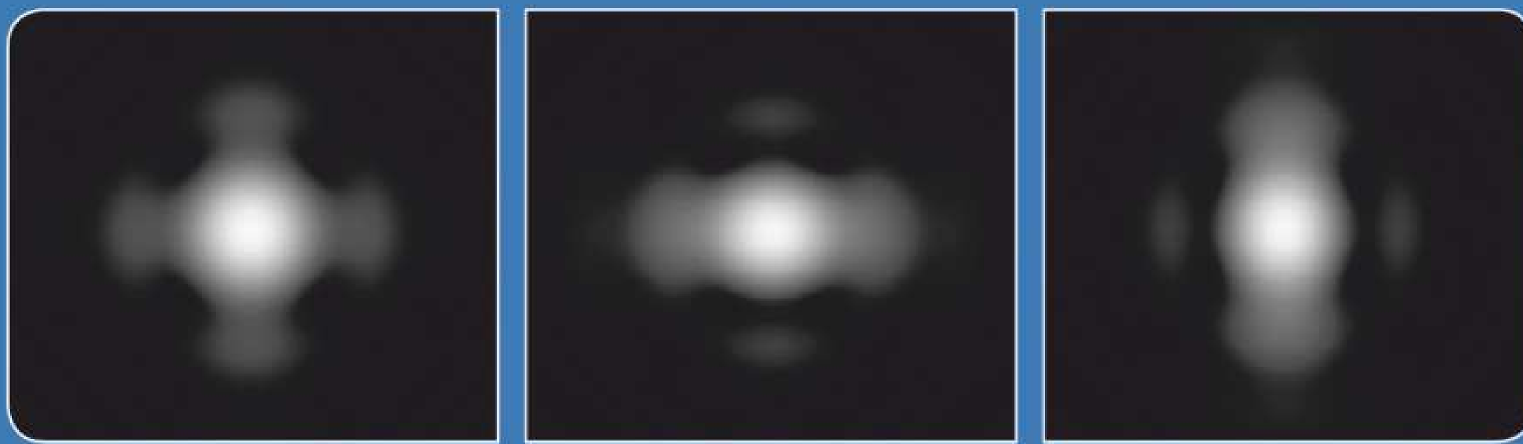
Finally, if you use a star diagonal, do the test with it both in and out of your scope. Remember, you're looking at the entire optical train, starting with the star and ending with your eyes and brain. I typically test optics the same way I observe. And remember, if your observing eye has some astigmatism, you'll see that in the star test. So, wear your glasses.

The test

When you look at a star at high magnification, you should see a small disk and a diffraction ring (or set of rings) surrounding it. That disk is the Airy disk, the best focused spot of light that a telescope with a circular aperture can make. In a perfect system with no obstructions (like a secondary mirror), the bulk of the light is concentrated in the Airy disk, with only a small amount spilling out to form a ring.

Pick a bright star at least 55° high. If your mount doesn't have a drive, you'll want to pick a star close to the celestial pole. Just how bright a star you'll need depends on your scope's aperture. A little experimentation goes a long way. Your eyepiece must show the Airy disk and a diffraction ring, otherwise you can't do the test. You may have to use slightly lower or higher power depending on conditions. Make sure you keep the star centered in the field of view to avoid eyepiece edge aberrations creeping in and confusing things.

If you see a broken diffraction ring, it probably means your scope is slightly miscollimated. If you see a comet-shaped blob, the problem could be several things, including severe miscollimation or coma. Both are fixable. It's worth the time to learn to collimate your telescope properly. That single action will do more to improve performance than anything else. The instruction manual that came with your scope



Astigmatism is characterized by a light bar that changes direction when you move from one side of focus to the other. The left image shows what this aberration looks like in focus; the other two show it on either side of focus. IMAGES GENERATED BY ABERRATOR (COR BERREVOETS)

will show you how to collimate it. And numerous online guides also exist.

By the way, coma is inherent in all Newtonian reflectors, but not unique to them. It's usually caused by miscollimation. Stars turn into comet-shaped blurs, and the problem gets progressively worse as you view from the center of your eyepiece's field to the edge.

Next, check for spherical aberration, which is common in mass-market reflectors. It indicates that the mirror was ground too shallow or too deep. To test for this, use the snap test. As you focus on the star (the Moon also works), is there a definite place where it snaps into focus, or is there a range where the focus is the same? The latter could be due to seeing or other factors, including spherical aberration. Observers call this range the "zone of confusion." There's no "best focus" with spherical aberration. The snap test reveals that a high percentage of the star's light winds up in the diffraction rings.

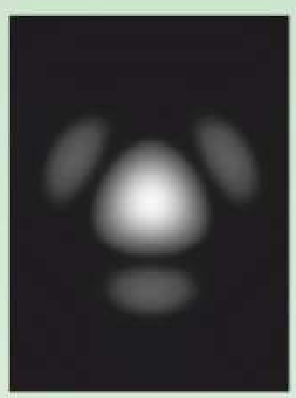
For the next test, aim at a star if you're not already pointed at one. Defocus slightly. Does the star look elongated? Now, roll your focus knob to the other side of focus. Did the direction of the elongation change? If so, that's astigmatism. But is it your telescope or your eye?

Rotate your head around the eyepiece. If the elongation moves as you turn your head, see your optometrist. If you're testing with a star diagonal, remove it and see if the astigmatism goes away. Pinched optics often cause this aberration. Give your scope some time to cool further and test again.

At some point, head over to the Moon to see how high a power you can use. Good optics should deliver a nice image between 30x and 40x per inch of aperture. Excellent optics can stretch it a bit beyond that, even as high as 60x per inch.

To get a good feel for your optics, repeat the entire process on several other nights. Never judge your scope by one session. Again, it bears repeating that evaluating optics — even in an informal approach such as this — is a demanding test of quality. Be prepared to forgive minor transgressions. Above all, remember to take a good look at the focused image. We don't waste time observing out-of-focus objects. Ultimately, the scope has to make you happy, and if you're satisfied, that's all that matters.

This star is deformed due to tube currents, which result from a mirror that hasn't reached ambient temperature. IMAGE GENERATED BY ABERRATOR (COR BERREVOETS)



Pinched optics happen when hold-down clips or collimation screws for mirrors are overtightened. IMAGE GENERATED BY ABERRATOR (COR BERREVOETS)

Tom Trusock *uses a variety of carefully tested telescopes to observe from his home in Ubly, Michigan.*

Other problems

The aforementioned procedure will give you a quick, basic evaluation. For other aberrations, you'll need to look at a star's image on both sides of focus. Here are two more that can occur in any optical design — and note that I've isolated all of these aberrations. In real life, you'll probably see a combination.

Field curvature: Ever seen a photo where the center is in focus, but the edges aren't? That's because the focal plane isn't actually a plane; it's a sphere. If you image through your scope, you'll probably wind up purchasing a field flattener to compensate for this.

Distortion: There are two types of distortion: rectilinear and angular. To envision rectilinear distortion, picture two parallel lines. If the lines curve inward (towards each other), your optics show pincushion distortion. If they curve outward, that's barrel distortion.

The other type is angular distortion. You'll see that objects become stretched out when you move them away from the center of the field of view. The most common proof of this distortion is if the Moon becomes egg shaped when you put it near the edge of the field.

Don't be discouraged

The first telescope I owned probably had the worst optics I've seen. It was a standard 8-inch "beginner's" Dobsonian-mounted Newtonian reflector I purchased from a popular company. At that time, it was customary for manufacturers to enclose the mirror in a couple of layers of particle board and duct tape for good measure. The problem was, the mirror never cooled down.

Furthermore, the secondary mirror was on a single stalk and impossible to align. The focuser was one step below a bad plumbing job, and the mount was so stiff, I constantly overshot my targets. With all that going against it, do I even need to talk about the quality of the optics?

My point, though, is that I got years of enjoyment out of that telescope. It was my first vehicle to the stars, and that makes me look back at it fondly. So, remember that a telescope is just a tool to help you explore the universe. Enjoy the journey. Don't sweat the tool. That said, a little star-testing will hone that tool into one you'll enjoy even more.

The CDK17 will allow you to capture spectacular celestial images. The author photographed his setup against a blue sky.

TESTING

PlaneWave's 17-inch scope

The search for your ultimate telescope may be over.

text and images by Tony Hallas

I have been doing astrophotography for 35 years. I started with film, then moved to film plus computers, and now I'm doing pure digital with CCD cameras. I've used telescopes of every type and size: Newtonians, Cassegrains, Ritchey-Chrétiens, and refractors. And each one had its own quirks. Some were hard to collimate; some changed their collimation when pointed to different parts of the sky; some defocused at the mere suggestion of temperature change; and some were not truly apochromatic, meaning all three colors were not focused at the same point.

All of this changed three months ago when I took possession of a PlaneWave CDK17 with quartz optics. I have never owned a telescope that worked perfectly, right out of the box. But even after a 400-mile (644 kilometers) journey from Los Angeles to my home in Foresthill, California, with the scope bouncing in the back of my pickup, the collimation was still perfect. Furthermore, when I point this telescope anywhere in the sky and turn it upside down — still no change.

The massive secondary mirror assembly ensures there will be no image shift as the CDK17 tracks targets across the sky.

High-quality manufacturing

Looking at the construction of the telescope, you can see why. Even the secondary mirror holder is a massive affair kept in place by solid spider vanes and supported by carbon fiber Serrurier trusses.

The scope weighs more than 100 pounds (45 kg) with accessories and a camera, so a substantial mount is necessary. One of the new PlaneWave L-Series mounts would be ideal. It's important to get a mount that will track at least two hours past the meridian to take advantage of the CDK17's rigidity and optical integrity.

The CDK17 is cooled by seven fans, three in the back and four arranged around the periphery of the front of the mirror. My routine is to start cooling as soon as the Sun goes down and to stop the fans when I start to image. By then, the scope's temperature usually is within 1 degree of ambient.

PlaneWave coats both mirrors with 96-percent-reflective enhanced aluminum.

When combined with the scope's f/6.8 focal ratio, that means you'll capture a lot in a single 20-minute exposure.

Optics

The optical design of the telescope bears explanation. CDK stands for corrected Dall-Kirkham — corrected because a Dall-Kirkham design by itself produces sharp images at the center of the field of view but has terrible aberrations away from that zone. PlaneWave's design uses an ellipsoidal primary combined with a spherical secondary and a two-element corrector lens housed at the bottom of the primary baffle tube. The baffle tube is made using a 3D printing process, and the tube is optimized to give a 70-millimeter image circle at the camera end with pinpoint stars to the edges.

The most important element in this optical design is the spherical secondary mirror. All regular Cassegrain reflectors must have the secondary centered exactly in front of the primary. The slightest misalignment will destroy the acuity of the telescope. But with a spherical secondary, exact centering is not critical as long as the secondary is collimated to the primary — an easy task that only takes minutes when it is needed. As mentioned earlier, I have yet to collimate my CDK17.

The CDK17 has an f-ratio of 6.8 and a focal length of nearly 3,000 millimeters. I ordered my telescope with certain accessories, the most important being the massive rotating focuser that easily can hold 40 pounds (18 kg) of camera gear. The scope also came with heaters on the back plate and the secondary, and includes temperature sensors on the secondary, the primary, and the back plate, plus one for the air temperature. The software will also keep the optics 1 degree above ambient on humid nights, preventing dew from forming without generating enough heat to distort the image.

The telescope is completely free of astigmatism, an issue that Dall-Kirkham telescopes have had in the past. PlaneWave's solution was a redesign of the mounting that allows the primary mirror to essentially float in the air, independent of any thermal stress that a more rigid mounting would create. Stars show identical patterns on either side of focus, a testament to the excellence of the optics.

Above: The author captured LRGB exposures through his CDK17 and created this image of spiral galaxy M101.

Right: As this image of NGC 6914 demonstrates, the color rendition of the CDK17 is top-notch.

Perfect focus

PlaneWave has created an amazing automated focusing routine. The telescope comes with a type of V-curve software that takes five images, changing the focus with each one. When the exposures are finished, it analyzes all the stars in the images, not just a few. After calculating the best focus position, the telescope then moves the focuser to that position. The quartz optics will hold that focus for the entire imaging session.

Initially I didn't trust automatic focusing. How could it be that easy? So, I would bracket manually around the calculated point to see if I could do better.

I couldn't.

It nails the focus every time. This process works with MaxIm software, and you can set up various schedules to refocus if need be, but with the quartz optics, I have found there is no need.

PRODUCT INFORMATION

PlaneWave CDK17
Optical design: Corrected Dall-Kirkham reflector
Aperture: 17 inches
Focal length: 2,939 millimeters
Focal ratio: f/6.8
Focuser: 2.5" two-speed rack-and-pinion
Length: 42 inches (106.7 centimeters)
Weight: 106 pounds (48 kilograms)
Price: $22,000
Contact: PlaneWave Instruments
1819 Kona Drive
Compton, CA 90220
www.planewave.com
310.639.1662

My technique

Here's how I use the telescope to acquire data: I first locate my target. Once my monitor displays it (via a link to my CCD camera), I fine-tune the cropping and rotation and take an exposure that will later serve as my cropping guide for future nights.

The telescope has been cooling for a while, but before I start imaging, I run the focus routine I described earlier. Depending on the object, I may take LRGB exposures or perhaps narrowband frames using scripting in MaxIm. If the Moon is partially up, I'll shoot the narrowband first and follow it with the LRGB.

Not all nights are the same, so I will shoot every clear night and reject any nights of bad seeing (a measure of the air's steadiness). I shoot darks and flats once I acquire all my data, and flats are easy to do with the CDK17 because the front of the telescope is flat. There's no focus motor protruding, so it's easy to hang a light panel on the front of the scope.

Final thoughts

The CDK17 has a history of constant improvements. This has been PlaneWave's philosophy through the years. I'm still looking for something — anything — that might be wrong with this telescope. I haven't found it yet. Is it a perfect telescope? It just might be.

Tony Hallas *is a contributing editor of* Astronomy *and a longtime astroimager.*

NEW PRODUCTS

Attention, manufacturers: To submit a product for this page, email **mbakich@astronomy.com**.

Monochrome camera

Orion Telescopes & Binoculars
Watsonville, California

Orion's StarShoot G4 Monochrome Deep Space Imaging Camera incorporates regulated thermoelectric cooling that keeps the camera at least 36 degrees Fahrenheit (20 degrees Celsius) below ambient temperature. The chip is a 0.5-inch Sony ICX829ALA CCD, which has a 752x582 pixel array.

$499.99
800.447.1001
www.telescope.com

Observing guide

Orion Telescopes & Binoculars
Watsonville, California

Orion's *Exploring the Cosmos: An Introduction to the Night Sky* provides fascinating facts about space. It begins with a look at our Sun and solar system and then moves outward. You'll learn to identify constellations as well as some of the myths behind them. The 48-page book measures 10.5 by 8.5 inches.

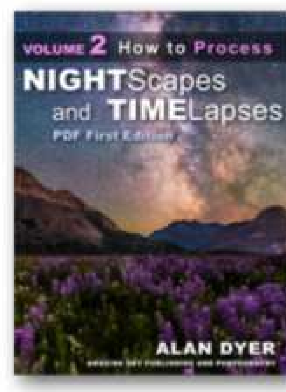
$12.99
800.447.1001
www.telescope.com

Imaging e-book

Alan Dyer
Strathmore, Alberta, Canada

Alan Dyer has added a second volume of *How to Photograph & Process Nightscapes and Timelapses*. This 425-page book, available on the Apple Store or in PDF format, includes 50 multipage tutorials, 18 HD videos demonstrating time-lapse techniques, and product reviews and tutorials.

$27.99
amazingsky@icloud.com
www.amazingsky.com



Spotting scope

Orion Telescopes & Binoculars
Watsonville, California

Orion's GrandView Vari-Angle 20–60x80mm Zoom Spotting Scope lets you view at any angle between 0° and 90°. The field of view varies from 1° at 60x to 1.8° at 20x. All optics are fully multicoated. The unit weighs 4.4 pounds (2 kilograms), and the optical tube is 18 inches (45.7 centimeters) long.

$399.99
800.447.1001
www.telescope.com

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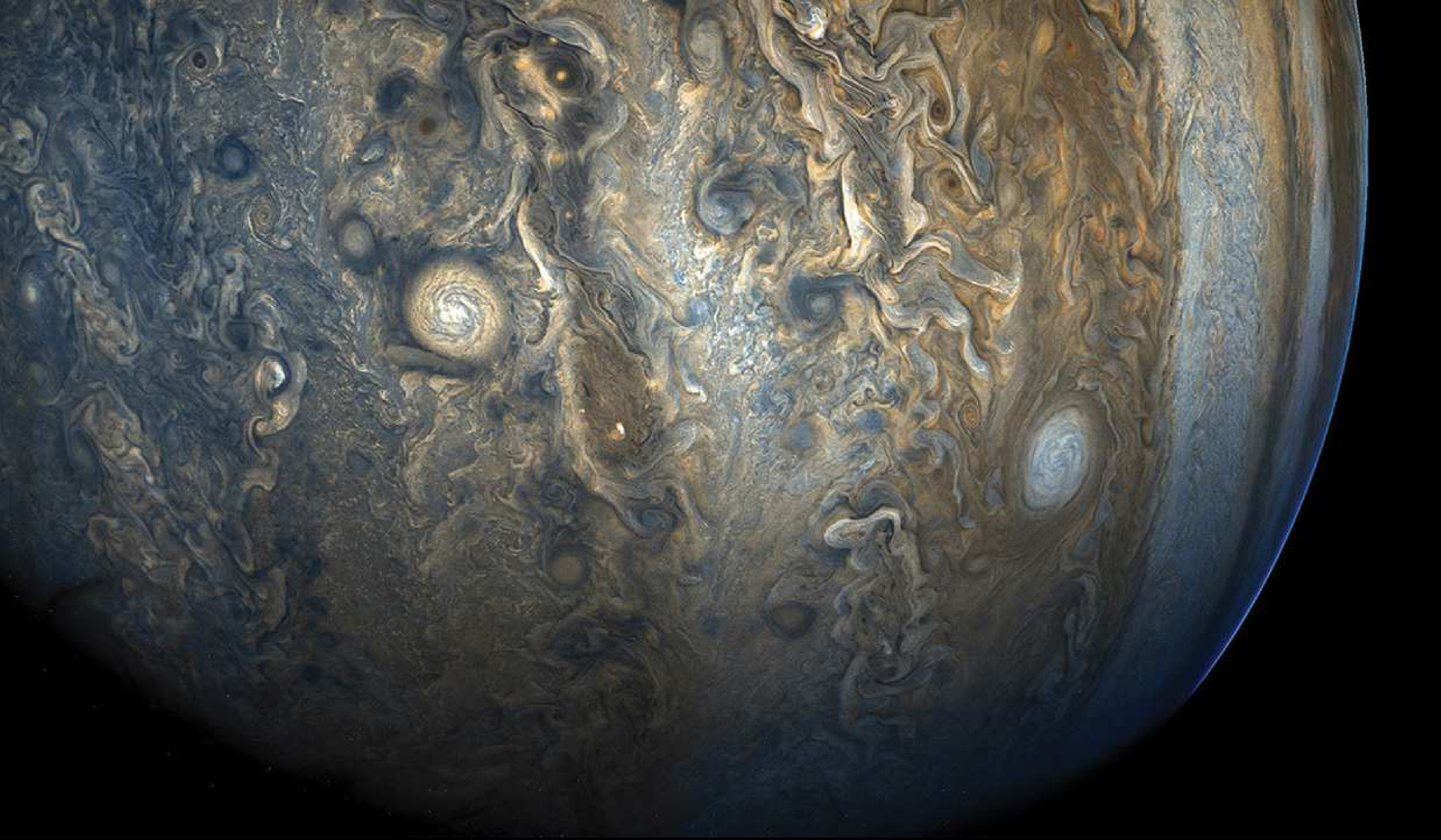
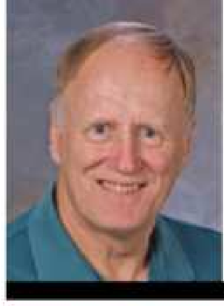




OBSERVING**BASICS**

BY GLENN CHAPLE

Sizing up the Super Moon

Although the term is usually a bit of a stretch, it fits the bill during this month's lunar eclipse.

Comparing lunar sizes from memory is tough. When the Full Moon reaches its closest point to Earth (perigee), it appears just 14 percent larger and about 30 percent brighter than when it's at its farthest (apogee). NASA/JPL-CALTECH

You're at a wine-tasting party. You pick up the first sample and take a sip. You then move on to the next glass — one month later. Not very practical is it? How can you evaluate different wines if 30 days pass between samples?

To me, it's the same when we compare the apparent sizes of Full Moons. Because the Moon's orbit isn't circular, a Full Moon can occur when the Moon is as far from Earth as it can get (apogee), or when it is as close as possible (perigee). A perigee Full Moon can be as much as 14 percent larger than an apogee Full Moon.

And here's my gripe. In recent years, news stations (usually via the weather reporter) refer to a perigee Full Moon as a "Super Moon." Astronomically naïve listeners rush outside, expecting to see a Full Moon filling the night sky. Instead, they see the same old ordinary Full Moon. And I'm with them. I've never noticed an obvious difference in the sizes of various Full Moons — not when they occur a month apart. Now, if you place an apogee Full Moon and perigee Full Moon side by side (something we can do photographically), the difference is obvious.

Here's my suggestion to the media: Don't refer to a perigee Full Moon as a "Super Moon." Call it what it is — a "larger-than-average Full Moon." Sadly, the idea will never fly. Not enough hyperbole.

Now that I've bashed the use of the term *Super Moon*, I'm going to tell you why this month's perigee Full Moon, slated for the evening of January 21/22, will indeed be a Super Moon. On that evening, the Moon will pass through Earth's shadow. Virtually everyone in North and South America, plus those living in Europe, east Africa, and Arctic regions, will be treated to a total lunar eclipse.

Although the eclipse will last more than five hours, you can skip the first and last hours when the Moon encounters the penumbra (the faintest part of Earth's shadow). Things get interesting with the onset of partiality at 10:34 P.M. EST as the Moon enters the umbra (the dark part of the Earth's shadow). Totality begins at 11:41 P.M. and ends at 12:43 A.M. Die-hards will stay on to view the closing partial phases, which last until the Moon leaves the umbra at 1:51 A.M. By the way, binoculars or a telescope are optional. As with any total lunar eclipse, this one can be enjoyed with the unaided eye.

Now that I've bashed the use of the term, I'm going to tell you why this month's perigee Full Moon will indeed be a Super Moon.

There are several reasons why people may opt out of this eclipse. It occurs at what is to many East Coast residents an ungodly hour, evening temperatures in northerly latitudes might be bone-chilling, and veteran skywatchers may harbor an "if you've seen one, you've seen 'em all" attitude. Don't let these excuses deter you from viewing this eclipse!

A total lunar eclipse is hardly a nightly event. The next one won't happen until May 26, 2021, and that one will only be visible from regions around the Pacific Ocean. Upcoming total lunar eclipses viewable from North America will occur on the evenings of May 15/16, 2022 (best seen in eastern locales) and November 8, 2022 (better viewed farther west). The next all-North America total lunar eclipse won't happen until March 13/14, 2025. Considering the possibility of cloudy weather on any eclipse night, it may be years before you see your next total lunar eclipse. If you absolutely need your beauty sleep, at least set your alarm clock for mid-eclipse (12:12 A.M. EST) for a quick view of the totally eclipsed Moon.

What about the possibility that Jack Frost may be nipping at your nose? Not to worry! No one says you have to stand outside in the snow for hours on end to capture every second of the eclipse. Every 10 to 15 minutes, bundle up and go outside for a quick peek.

And lose that "been there, done that" attitude! During a typical total lunar eclipse, the Moon takes on the eerie coppery red color that must have frightened pre-civilized humans. This "Blood Moon" results from the same refractive effect that causes the setting Sun to appear reddish and fills the umbra with a similar ruddy hue. Excessive cloudiness, dust from forest fires and desert wind storms, and ash from volcanic eruptions can change the rules. Depending on the condition of Earth's atmosphere, a totally eclipsed Moon can appear unusually bright or so dark it is nearly invisible. We never know exactly how the fully eclipsed Moon will look.

Scribble in "Total Lunar Eclipse — Night of January 21/22" on that magnetic whiteboard you keep on your refrigerator. This time when people rush outside to see a "Super Moon," they'll truly be greeted by a super Moon!

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: An in-depth look at the Orion Nebula. Clear skies!

Glenn Chaple has been an avid observer since a friend showed him Saturn through a small backyard scope in 1963.

BROWSE THE "OBSERVING BASICS" ARCHIVE AT **www.Astronomy.com/Chaple.**

BINOCULARUNIVERSE
BY PHIL HARRINGTON

Little-known Taurus treats

Cool clusters for cold winter nights.

The V-shaped Hyades star cluster is one of the closest such objects to us and makes a magnificent sight in any binoculars. JOHN CHUMACK

In his 1888 book *Astronomy with an Opera-Glass*, Garrett Serviss wrote, "I have never beheld the first indications of the [winter stars] without a peculiar feeling of awakened expectation, like that of one who sees the curtain rise upon a drama of absorbing interest. … First in the east come the world-renowned Pleiades. … In an hour the fiery gleam of Aldebaran appears at the edge of the dome [along with] the beautiful V-shaped group of the Hyades."

Just as Serviss promised his readers 130 years ago, we, too, witness the beauty and anticipation of the coming winter stars and the many beautiful sights that they bring.

When we look toward the stars of the **Hyades**, we are admiring one of the open star clusters nearest to our solar system. All the stars in the naked-eye V, as well as many more visible through binoculars, collectively lie an average of 151 light-years away. All, that is, except for Aldebaran, the Bull's angry red eye. It's only 65 light-years from us, so is not a true cluster member. We visited the Hyades in this column back in January 2017, so be sure to take a look at that issue for further discussion of this spectacular target.

As you admire the view of the Hyades, take a quick glance to their north. There, you'll find another collection of a dozen or so stars that, although not a formal cluster, are a pretty sight nonetheless. You'll probably first notice a close-set pair of stars, Kappa^1 (κ^1) and Kappa^2 (κ^2) Tauri, as well as Omega (ω) Tauri to their southwest and other fainter suns filling the space between. While they may just look like a random scattering at first, the creative mind of the late Massachusetts amateur astronomer John Davis saw the shape of a dog. In his words, **Davis' Dog** looks like a "cute little dog whose nose got caught in a pencil sharpener!" Omega marks the tip of the sharpened nose, while fainter 53 Tauri represents one of the hound's eyes. The stars 51 and 56 Tauri lie at the tips of the dog's pointy ears. The dog's tail arcs from the two Kappas to 69 and 72 Tauri, while the body and legs are formed from two fainter triangular patterns to the south. In all, Davis' Dog spans an area 3° by 1°.

The V pattern of the Hyades naturally draws our eyes toward the tips of the Bull's horns, marked by Elnath [Beta (β) Tauri] and Zeta (ζ) Tauri. But rather than jump directly there, take a slow and deliberate stroll in their direction while viewing through your binoculars.

Not even a full field beyond the Hyades, you will come to a softly glowing patch of faint light. That's **NGC 1647**, an open cluster of 200 stars residing 1,800 light-years away. You'll know you're in the right place when you spot a tightly set pair of orangish stars, 6th-magnitude SAO 94112 and 8th-magnitude SAO 94110. Both overlap the cluster's southern edge, but are much closer to us than the cluster itself.

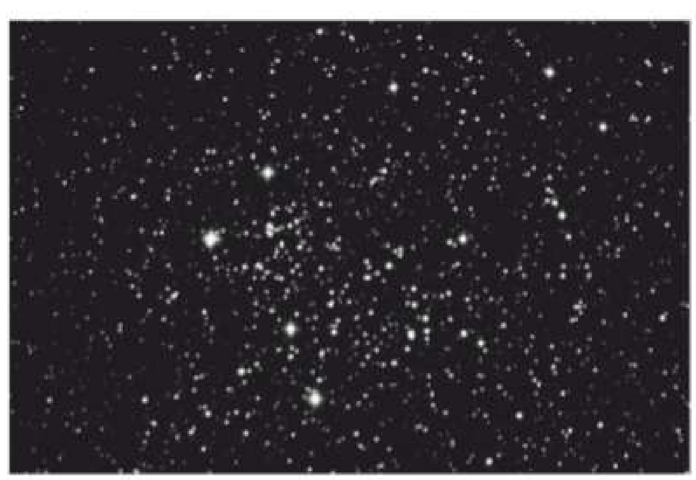
Like the Hyades, NGC 1647 looks better through binoculars than through many telescopes. That's because its stars span an area of sky larger than that covered by the Full Moon. Through my 10x50 binoculars, I count half a dozen or so dim points of light poking out through the mist of fainter, unresolved cluster stars. With averted vision, you may notice that the cluster has an overall triangular or diamond shape.

There's a second open cluster lying between the Bull's horns, about halfway between the Hyades and Elnath. **NGC 1746** strikes me as more obvious than its neighbor, even though it doesn't share the same hazy look. That's because its stars are more scattered. Most binoculars will show 12 to 15 suns shining between magnitudes 5 and 9. Through my 16x70 binoculars, I noticed that a couple of the cluster stars show subtle reddish tints that went undetected in my 10x50s. Can you spot them? You may also spot five stars zigzagging along the southern edge of the cluster. They remind me of a distorted Cassiopeia W.

We will return to Taurus next month to hunt for the remains of a long-gone star, as well as tiptoe into nearby Gemini. Meanwhile, if you have a favorite binocular object, I'd love to hear about it and possibly feature your observations in a future column. Drop me a line through my website, philharrington.net.

Until next month, remember that two eyes are better than one.

The sprawling open cluster NGC 1647 offers rich, bright stars visible in a binocular field of view. ANTHONY AYIOMAMITIS



Bright, scattered stars make up the binocular open cluster NGC 1746. MARTIN C. GERMANO

Phil Harrington is a longtime contributor to Astronomy *and the author of many books.*

THE FIRST ELEMENT

Q: HOW DID THE FIRST CHEMICAL ELEMENT APPEAR IN THE UNIVERSE?

Candy Ye, *Melbourne, Australia*

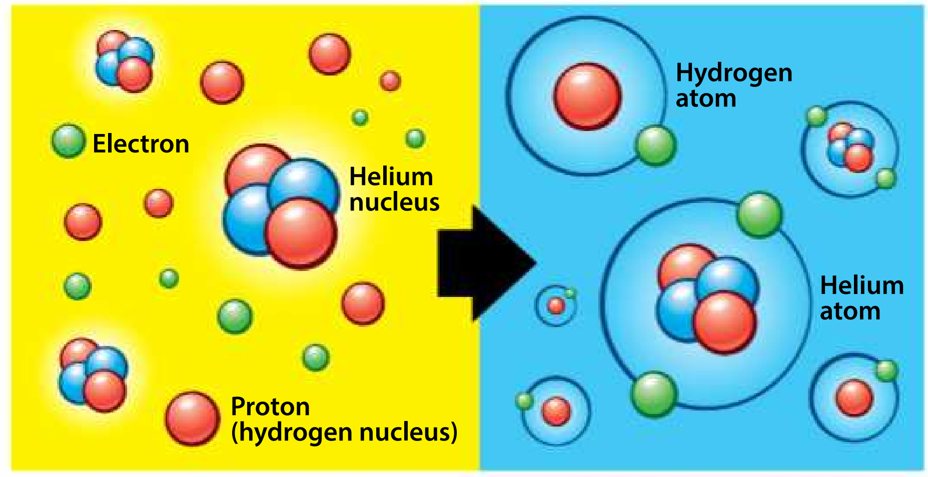
A: Immediately (much less than a second) after the Big Bang, the universe was both too hot and too dense for elements to form. Hydrogen didn't appear until the universe had spread out — and subsequently cooled — enough for the first protons and neutrons, and later simple atoms, to form.

Between about 10^{-12} and 10^{-6} second after the Big Bang, neutrinos, quarks, and electrons formed. Protons and neutrons began forming shortly after, from about 10^{-6} to 1 second after the Big Bang. Within about 3 minutes after the Big Bang, conditions cooled enough for these protons and neutrons to form hydrogen nuclei. This is called the era of nucleosynthesis. Some of these nuclei combined to form helium as well, though in much smaller quantities (just a few percent). But after about 20 minutes, nucleosynthesis ended and no further nuclei could form.

The problem at this point was that electrons couldn't stay in orbit around any atomic nucleus because of the immense heat and radiation still flooding the universe. Shortly after any neutral atoms would form (neutral atoms simply contain the same number of protons and electrons, and thus carry no overall charge), they were knocked apart again by energetic radiation.

Finally, after 380,000 years or so, the universe had again expanded and cooled enough for conditions to favor electrons staying in orbit around atomic nuclei. This is when recombination occurred — neutral hydrogen (and helium) finally appeared because they could "recombine with" (hold on to) electrons without easily losing them to stray radiation. If that number sounds familiar, it should — 380,000 years after the Big Bang is also the time when the cosmic microwave background was generated, because the atoms that formed entered their lowest energy state quickly after, releasing excess energy in the form of photons that could finally travel freely through the universe without knocking into anything along the way. This is the light that makes up the cosmic microwave background.

Alison Klesman
Associate Editor



The early universe (left) was too hot for electrons to remain bound to atoms. The first elements — hydrogen and helium — couldn't form until the universe had cooled enough to allow their nuclei to capture electrons (right), about 380,000 years after the Big Bang. *ASTRONOMY:* ROEN KELLY

Q: HOW CAN A GALAXY BE OVER 27 BILLION LIGHT-YEARS FROM EARTH IF THE UNIVERSE IS ONLY ABOUT 13 BILLION YEARS OLD?

Edward Perry
Lacey, Washington

A: The universe is indeed about 13.8 billion years old, based on measurements taken by the Planck mission in 2012.

Measuring something 27 billion light-years away from Earth — remember that a light-year is a unit of *distance* that describes how far you can go in one year at the speed of light, almost 6 trillion miles (9 trillion kilometers) — does seem inconsistent with there having only been 13.8 billion years for that light to have done any traveling. In fact, there are two things going on that remove the inconsistency here.

The first is that our universe isn't static. If the universe were not expanding, and had been at its current size for all of history, there'd be no way to fix this apparent paradox. A galaxy that's 10 billion light-years distant would still be 10 billion light-years away no matter how many billions of years you keep watching. Our universe is, however, expanding — and it's expanding faster as time progresses. So over time, two galaxies will drift farther apart from each other like driftwood in a current.

The second factor is that we're not *directly* measuring a galaxy at 27 billion light-years away from us — we're seeing ancient light from that galaxy, which has traveled for billions of years through the universe. The universe was smaller (and younger) when the light initially left; this younger, shorter path only takes a few billion years to reach us. In that time, though, the universe has expanded, and the distance between us and the galaxy is now much greater — so much greater that if the light were to make the journey today, it would take 27 billion years to reach us. This is, of course, not something we can observe now — there simply hasn't been enough time since the universe's birth for light to travel that far. But given our understanding of how the universe is changing, we can predict how far the galaxy should now be (27 billion light-years), based on the light we receive that was emitted in the past.

Jillian Scudder
Assistant Professor of Physics, Department of Physics, Oberlin College and Conservatory, Oberlin, Ohio

Q: IS POLARIS VISIBLE FROM ANY LATITUDE SOUTH OF THE EQUATOR?

Jim Clark
Watauga, Texas

A: If conditions are just right, you can see Polaris from just south of the equator. To find out how far south, let's first set a few ground rules. We'll assume a hypothetical skygazer viewing from sea level with a perfectly flat horizon toward the north. And we'll further assume ideal sky conditions that allow our observer to see a 2nd-magnitude star (like Polaris) right on the horizon.

Although Polaris is also known as the North Star, it doesn't lie precisely above Earth's North Pole. If it did, Polaris would have a declination of exactly 90°. Instead, our

navigational beacon currently has a declination of 89.34°. The difference, 0.66°, would be Polaris' peak altitude if viewed from the equator, and the latitude south of the equator from which the star would scrape the horizon — if Earth had no atmosphere. But our blanket of air refracts starlight, causing an object near the horizon to appear higher than it really is. Under typical atmospheric conditions, this adds 0.57° to an object's altitude, so Polaris would barely show up from 1.23° south latitude.

But all this assumes you're viewing in 2018. The gravitational pulls of the Sun and Moon cause Earth's axis to precess slowly. During a 25,800-year cycle, the position of Earth's axis in space traces out a 46.88°-wide circle on the sky. In 12,600 years, Polaris will reach its lowest declination of 44.62°. At that time, Polaris will be visible anywhere north of 45.95° south latitude (90°–44.62°+0.57°), and our current "North Star" will grace the skies above all of Africa and Australia.

Richard Talcott
Senior Editor

Q: I'M CURIOUS ABOUT THE MECHANISM IN JUNE'S "WATER WORLDS IN THE MILKY WAY" THAT CAUSES ORBITING PLANETS TO SPIRAL IN UNTIL THEY ARE TORN APART BY A WHITE DWARF. WHAT CAUSES THEM TO MOVE INWARD, AND ON WHAT TIMESCALE?

Michael Hickman
Centerville, Texas

A: To answer these questions, we must take a step back and add a layer to the article. The best place to start is right here in the solar system.

First, when our Sun finishes fusing matter into energy, it will expand. Some astronomers call this process "death," but really it's a transformation, more like a caterpillar changing into a butterfly. The Sun will almost certainly engulf Mercury and Venus and consume them utterly, and while the fate of Earth is uncertain, everything exterior to Earth's orbit will remain essentially intact. This includes Mars, the main belt of asteroids, the giant planets, and beyond. When the Sun later shrinks and heats up into an Earth-sized ember known as a white dwarf, it will remain surrounded by a fairly complex planetary system.

Second, Jupiter currently has a dramatic gravitational influence on the asteroid belt (and to a lesser degree, Neptune influences the Kuiper Belt, where Pluto and many other icy objects reside). Jupiter is basically a bully — the asteroids want to come together to form a small planet, but Jupiter keeps the potential family members separated by pushing and pulling on anything in certain regions of the main belt, emptying these areas out. The emptied regions of the main belt are called the Kirkwood gaps, and Jupiter shoves things out of the gaps via something called orbital (or mean-motion) resonances, which work like pushing someone on a swing. For example, an asteroid with a 2:1 resonance with Jupiter orbits the Sun twice for every one orbit Jupiter makes. Once every two orbits, the asteroid will line up with Jupiter, which acts like the person pushing the swing to tug the asteroid out of its original orbit, clearing the gap.

These "lost" asteroids can be ejected from the solar system, bang into another planet, or fall into the Sun. We sometimes see the latter with the Solar and Heliospheric Observatory (SOHO) and Solar TErrestrial RElations Observatory

An icy, rocky body is torn apart by the gravity of the white dwarf GD 61 in this artist's impression. Such bodies likely end up on devastating trajectories through gravitational interactions with a planet. NASA, ESA, M.A. GARLICK (SPACE-ART.CO.UK), UNIVERSITY OF WARWICK, AND UNIVERSITY OF CAMBRIDGE

(STEREO) satellites, although these are usually small bodies, so it happens quickly. But this process certainly happens to large bodies on timescales longer than our lifetimes. In fact, the most common effect of a mean-motion resonance is to change the affected object's orbital eccentricity, which measures how circular its orbit appears from overhead. The larger an orbit's eccentricity, the more elliptical and less like a circle it appears.

This changing eccentricity is what astronomers envision for the tidally destroyed planetary bodies at white dwarfs. There is a surviving planetary system, and gravitational interactions between at least one planet and any surviving asteroids (or comets) lead to high-eccentricity orbits. These orbits can then intersect with the white dwarf's Roche radius — the distance at which tidal gravity from the star tears apart any body — which will destroy the object and result in a cloud or disk of debris that will eventually rain down onto the stellar surface. This is what causes the metal pollution we observe and allows us to obtain the composition of this doomed little world.

As for the timescale, the gravitational disturbance occurs on the orbital timescale of the planetary body in question (i.e., the time it takes to complete an orbit). However, simulations have shown that this can occur right away within several million years after the white dwarf forms, and continue for many billions of years as the white dwarf gradually cools. All that is required is at least one planet and a sufficient reservoir of bodies to throw around.

Jay Farihi
Reader in Astrophysics, Department of Physics and Astronomy, University College London, United Kingdom

Send us your questions

Send your astronomy questions via email to **askastro@astronomy.com**, or write to Ask Astro, P. O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

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1. Outside-county	-0-	-0-
2. In-county	-0-	-0-
3. Other classes mailed through the USPS	229	228
4. Outside the mail	58	-0-
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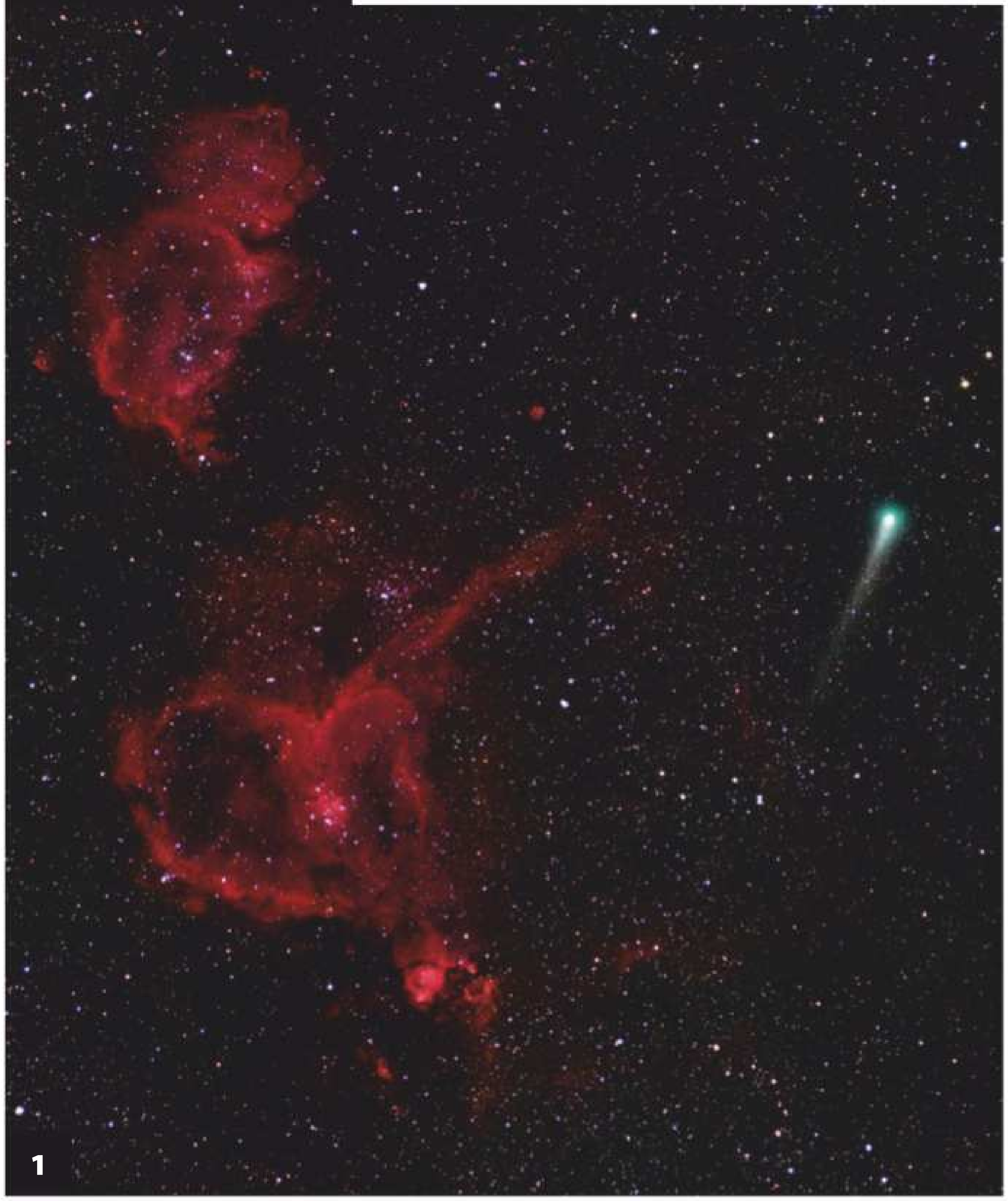

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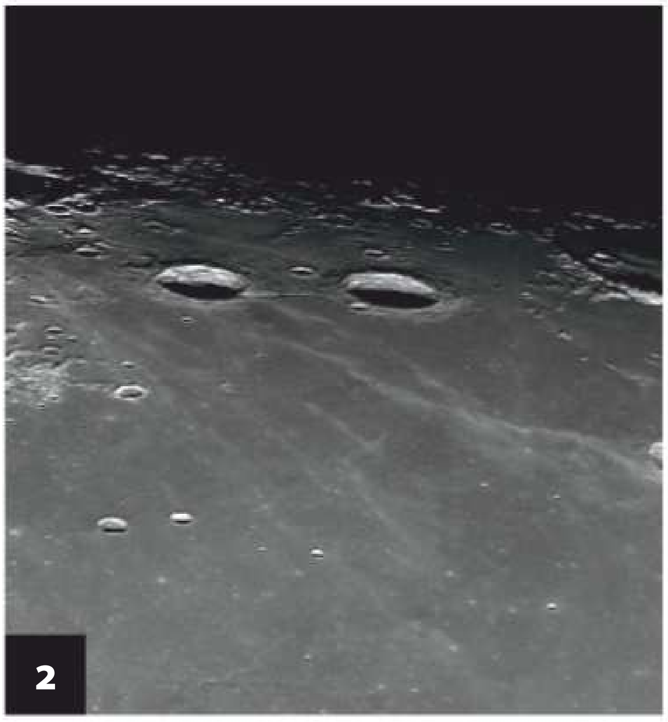

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1. A COMET WITH SOUL
Comet 21P/Giacobini-Zinner passes the region of space inhabited by the Heart and Soul nebulae (IC 1805, bottom, and IC 1848) on Aug. 16, 2018. The blue-green comet stands in stark contrast against the reddish emission nebulae in Cassiopeia. • ***Gerald Rhemann***

2. TWO FOR THE MONEY
Lunar craters Cardanus (left) and Krafft lie on the shore of Oceanus Procellarum on the far western edge of the Moon. Each has a diameter of 30 miles (50 kilometers), and they are connected by a hard-to-see catena (crater chain). North is to the left. • ***Brian Ford***

3. PERSEIDS!
The photographer set up two identical cameras to capture exposures of the Perseid meteor shower during the night of Aug. 13 and the morning of Aug. 14th, 2018. The final product shows three hours of shooting with all exposures aligned and placed atop a three-pane background panorama. • ***Tony Hallas***

4


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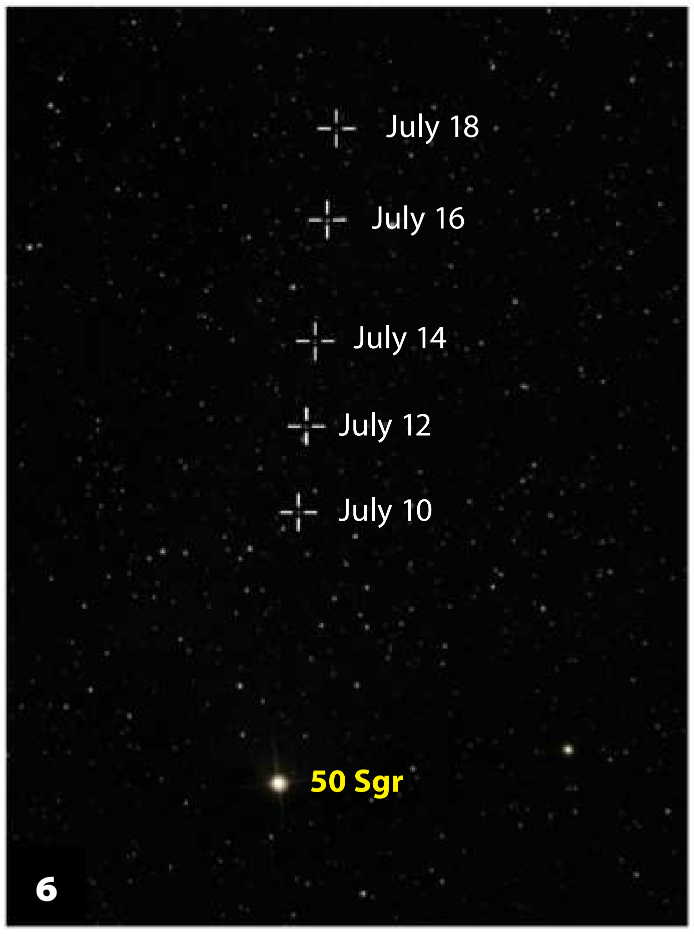

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4. FAR FROM THE SUN
Mercury (top) and Venus are easy to spot after sunset March 15, 2018. The photographer took this shot at 7:53 P.M. from Radio Road, about a mile east of Highway 13, northeast of Marion, Iowa. Mercury reached greatest elongation on this date. ***• Gregg Alliss***

5. SHADOWY ENCOUNTER
The fully eclipsed Moon stands above Los Gigantes in Cibola County, New Mexico, on Jan. 31, 2018, at 6:39 A.M. Although the sky is brightening, a few stars remain visible. ***• Dane Lambson***

6. SLOW BUT STEADY
This combination of five exposures captures the motion of Pluto over 11 nights in 2018. On average, it takes Pluto 130 days to travel through our sky a distance equal to the width of the Full Moon. The star 50 Sagittarii glows at magnitude 5.6. ***• Kfir Simon***

7. GASSY CLUSTER
Melotte 15 is a recently formed open cluster buried within the magnificent Heart Nebula (IC 1805). Stellar winds from cluster members sculpt the complex structure of the hydrogen clouds. This region of space lies within the constellation Cassiopeia some 7,500 light-years away. ***• Michael P. Caligiuri***

8. ULTRA-SOUTHERN SKY
NGC 7098 is a gorgeous barred spiral galaxy in Octans, the constellation that surrounds the South Celestial Pole. It lies about 95 million light-years from Earth and spans roughly 150,000 light-years. ***• Geoff Smith***

Send your images to:
Astronomy Reader Gallery, P. O. Box 1612, Waukesha, WI 53187. Please include the date and location of the image and complete photo data: telescope, camera, filters, and exposures. Submit images by email to readergallery@astronomy.com.

BREAK THROUGH

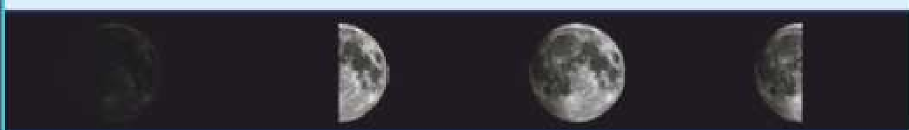
A wolf bites a scorpion

Like thick clouds of smoke billowing into a clear sky, dark clouds of dust snake through the star-forming region called Lupus 3 in western Scorpius the Scorpion. This expanse belongs to a bigger complex called the Lupus Clouds, centered in neighboring Lupus the Wolf. At a distance of 600 light-years, Lupus 3 ranks among the closest stellar nurseries. While most of the light from newly formed stars remains hidden behind dust and cold gas, the two 7th-magnitude bluish stars at center have started to emerge from this cocoon. Astronomers captured the scene through telescopes at Paranal and La Silla observatories in Chile. ESO/R. COLOMBARI

Astronomy's 2019 Guide to the Night Sky

SPECIAL Pull-out section

LUNAR PHASES



New	First Quarter	Full	Last Quarter
Jan. 5	Jan. 14	Jan. 21	Jan. 27
Feb. 4	Feb. 12	Feb. 19	Feb. 26
March 6	March 14	March 20	March 28
April 5	April 12	April 19	April 26
May 4	May 11	May 18	May 26
June 3	June 10	June 17	June 25
July 2	July 9	July 16	July 24
July 31	Aug. 7	Aug. 15	Aug. 23
Aug. 30	Sept. 5	Sept. 14	Sept. 21
Sept. 28	Oct. 5	Oct. 13	Oct. 21
Oct. 27	Nov. 4	Nov. 12	Nov. 19
Nov. 26	Dec. 4	Dec. 12	Dec. 18
Dec. 26			

All dates are for the Eastern time zone. A Full Moon rises at sunset and remains visible all night; a New Moon crosses the sky with the Sun and can't be seen.

THE MOON is Earth's nearest neighbor and the only celestial object humans have visited. Because of its changing position relative to the Sun and Earth, the Moon appears to go through phases, from a slender crescent to Full Moon and back. The best times to observe our satellite through a telescope come a few days on either side of its two Quarter phases. For the best detail, look along the terminator — the line separating the sunlit and dark parts. NASA/GSFC/ARIZONA STATE UNIVERSITY

VENUS spends the first half of 2019 in the morning sky. The brilliant planet appears farthest from the Sun in early January, when it stands some 25° high in the southeast an hour before sunrise. It then shines at magnitude –4.6, more than 10 times brighter than the sky's second-brightest point of light, Jupiter. Venus disappears in the Sun's glow in early July, but returns to view after sunset in October. It remains a fixture in the evening sky through the end of the year. NASA

JUPITER always shows a dramatic face. Its atmosphere displays an alternating series of bright zones and darker belts pocked by the Great Red Spot. Even through a small telescope, the planet's four big moons appear prominent. You often will see them change positions noticeably during the course of a single night. Jupiter reaches its peak in June, when it shines brightest (magnitude –2.6) and looms largest (46" across), though it's a fine sight from the beginning of the year through early December. NASA/JPL/USGS

SATURN and its rings provide a spectacular attraction for telescope owners during most of 2019. The ringed planet is on display from late January through mid-December, but it appears best around the time of opposition in early July. Saturn then shines at magnitude 0.1, and its disk measures 18" across while the rings span 42" and tilt 24° to our line of sight. Even a small telescope reveals the dark, broad Cassini Division that separates the outer A ring from the brighter B ring.

NASA/ESA/E. KARKOSCHKA (UNIVERSITY OF ARIZONA)

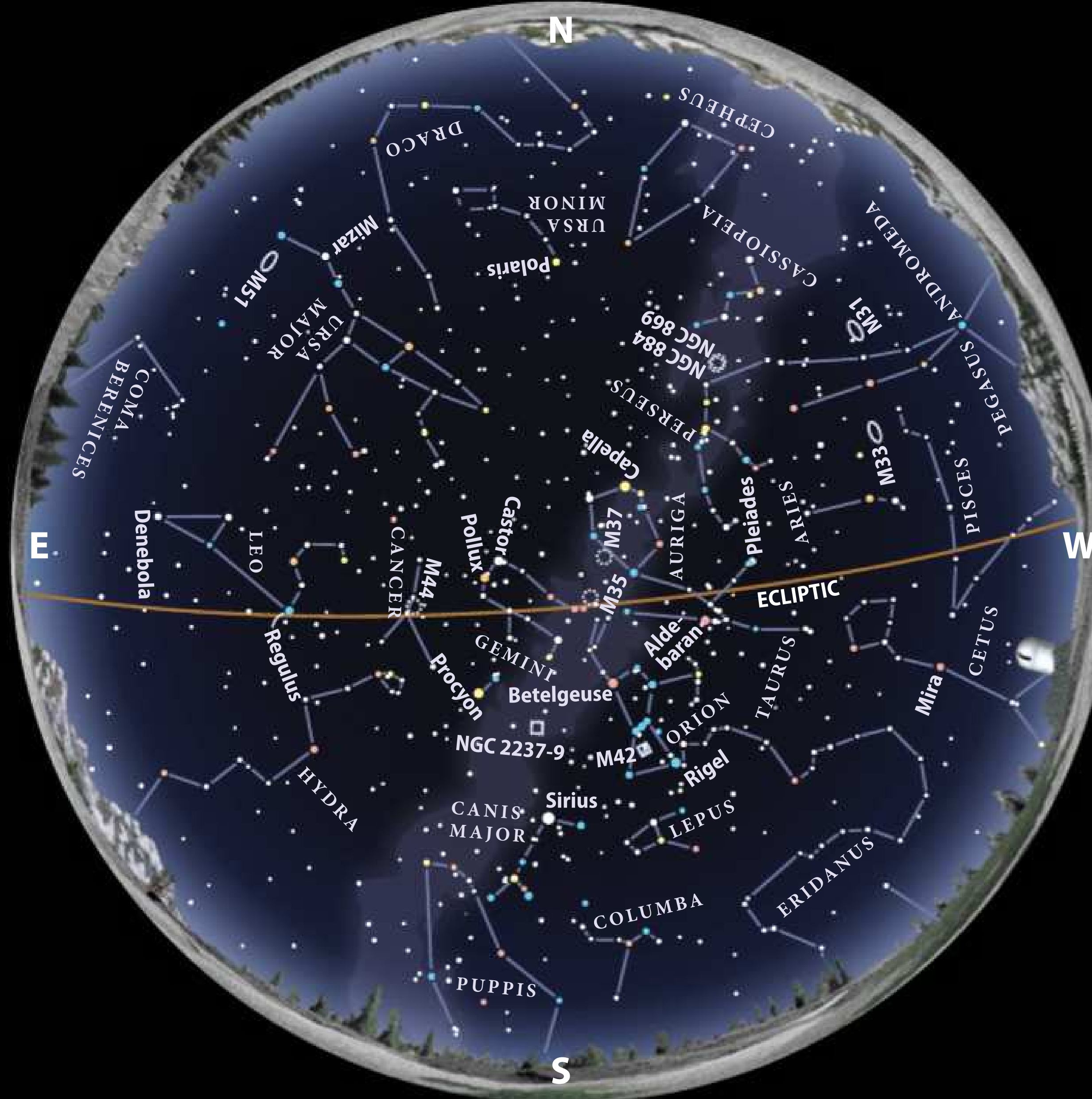
WINTER

The sky

Winter boasts the brightest stars of any season. Orion the Hunter dominates the evening sky this time of year. Its seven brightest stars form a distinctive hourglass pattern. The bright blue star marking Orion's left foot is Rigel, and the ruddy gem at his right shoulder is Betelgeuse. The three stars of the Hunter's belt point down to Sirius, the brightest star in the night sky, and up to Aldebaran, the eye of Taurus the Bull. To Orion's upper left lies the constellation Gemini.

Deep-sky highlights

The Pleiades (M45) is the brightest star cluster in the sky. It looks like a small dipper, but it is not the Little Dipper.
The Orion Nebula (M42), a region of active star formation, is a showpiece through telescopes of all sizes.
The Rosette Nebula (NGC 2237–9/46), located 10° east of Betelgeuse, presents an impressive cluster of stars and a nebula.
M35 in Gemini the Twins is a beautiful open cluster best viewed with a telescope.
Castor (Alpha [α] Geminorum) is easy to split into two components with a small telescope, but the system actually consists of six stars.



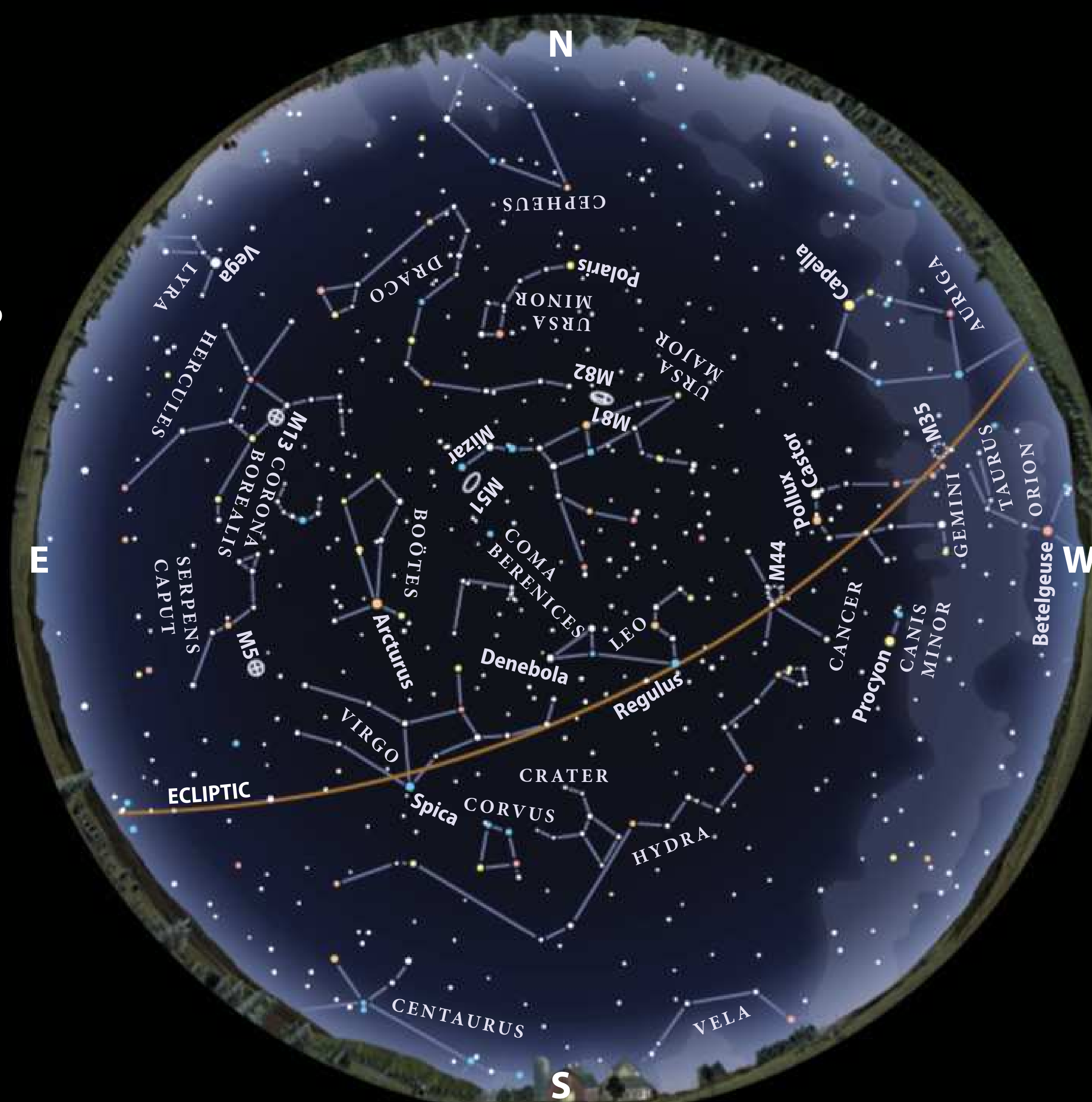
SPRING

The sky

The Big Dipper, the most conspicuous part of the constellation Ursa Major the Great Bear, now rides high in the sky. Poke a hole in the bottom of the Dipper's bowl, and the water would fall on the back of Leo the Lion. The two stars at the end of the bowl, called the Pointer Stars, lead you directly to Polaris, the North Star: From the bowl's top, simply go five times the distance between the Pointers. Spring is the best time of year to observe a multitude of galaxies. Many of these far-flung island universes, containing hundreds of billions of stars, congregate in northern Virgo and Coma Berenices.

Deep-sky highlights

The Beehive Cluster (M44) was used to forecast weather in antiquity. It is a naked-eye object under a clear, dark sky, but it disappears under less optimal conditions.
M5, a conspicuous globular cluster, lies between the figures of Virgo the Maiden and Serpens Caput the Serpent's Head.
The Whirlpool Galaxy (M51) is a vast spiral about 30 million light-years away.
M81 and **M82** in Ursa Major form a pair of galaxies that you can spot through a telescope at low power.



Jan. 3 Quadrantid meteor shower peaks

Jan. 5 Venus is at greatest western elongation

Jan. 20 Total lunar eclipse

Jan. 22 Venus passes 2° north of Jupiter

Feb. 18 Venus passes 1.1° north of Saturn

Feb. 26 Mercury is at greatest eastern elongation

May 6 Eta Aquariid meteor shower peaks

May 28 Dwarf planet Ceres is at opposition

June 10 Jupiter is at opposition

June 23 Mercury is at greatest eastern elongation

July 2 Total solar eclipse

STAR MAPS BY *ASTRONOMY*: ROEN KELLY

July 9
Saturn is at opposition

July 14
Pluto is at opposition

Aug. 9
Mercury is at greatest western elongation

Aug. 13
Perseid meteor shower peaks

Sept. 10
Neptune is at opposition

Oct. 21
Orionid meteor shower peaks

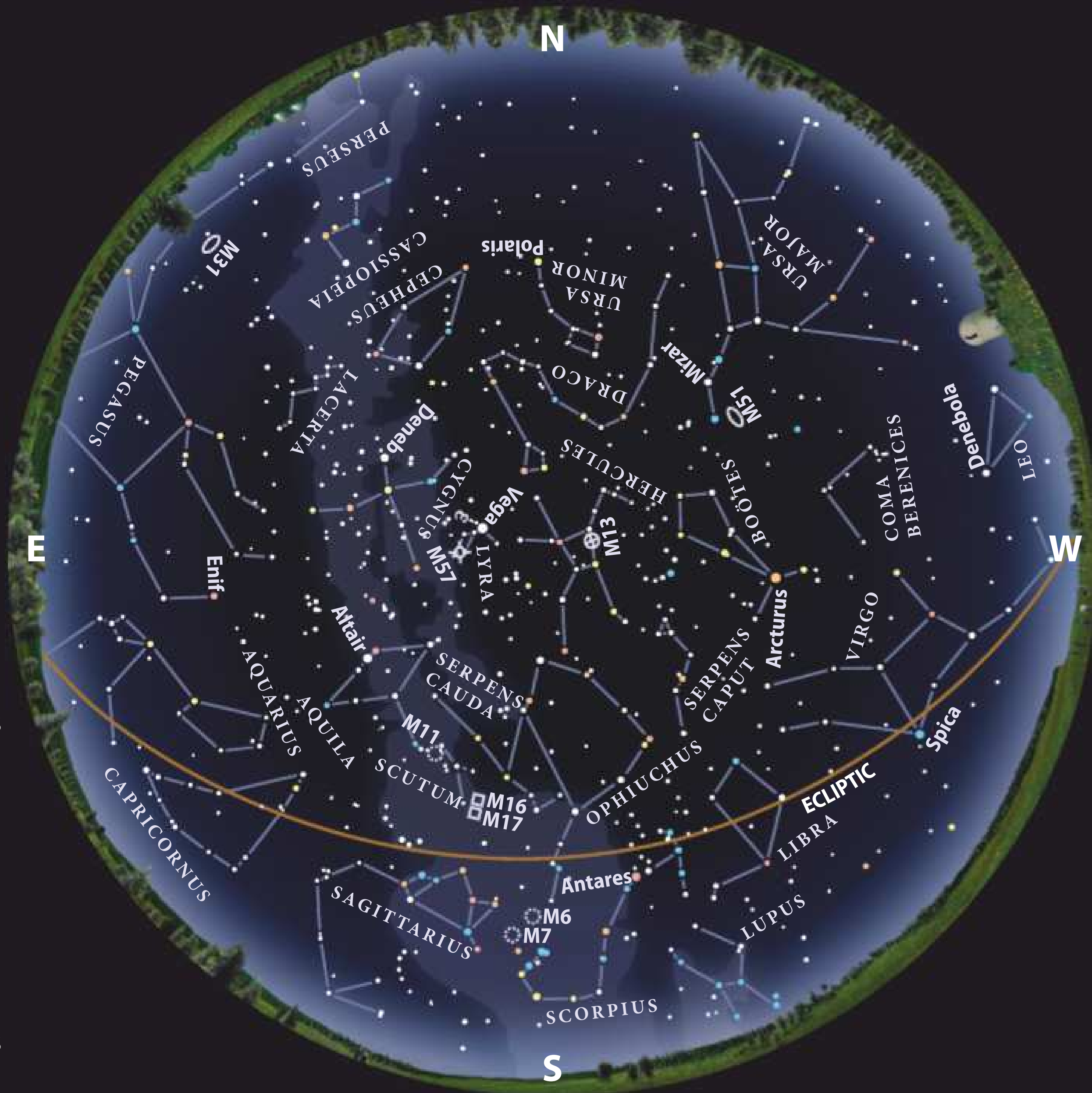
Oct. 28
Uranus is at opposition

Nov. 11
Mercury transits the Sun

Nov. 12
Asteroid Vesta is at opposition

Nov. 28
Mercury is at greatest western elongation

Dec. 14
Geminid meteor shower peaks



Open cluster
Globular cluster
Diffuse nebula
Planetary nebula
Galaxy

SUMMER

The sky

High in the sky, the three bright stars known as the Summer Triangle are easy to spot. These luminaries — Vega in Lyra, Deneb in Cygnus, and Altair in Aquila — lie near the starry path of the Milky Way. Following the Milky Way south from Aquila, you'll find the center of our galaxy in the constellation Sagittarius the Archer. Here lie countless star clusters and glowing gas clouds. Just west of Sagittarius lies Scorpius the Scorpion, which contains the red supergiant star Antares as well as M6 and M7, two brilliant clusters that look marvelous at low power.

Deep-sky highlights

The Hercules Cluster (M13) contains nearly a million stars and is the finest globular cluster in the northern sky.

The Ring Nebula (M57) looks like a puff of smoke through a medium-sized telescope.

The Omega Nebula (M17) looks like the Greek letter of its name (Ω) through a telescope at low power. This object also is called the Swan Nebula.

The Wild Duck Cluster (M11) is a glorious open star cluster. On a moonless night, a small scope will show you some 50 stars.

AUTUMN

The sky

The Big Dipper swings low this season, and from parts of the southern United States, it even sets. With the coming of cooler nights, Pegasus the Winged Horse rides high in the sky as the rich summer Milky Way descends in the west. Fomalhaut, a solitary bright star, lies low in the south. The magnificent Andromeda Galaxy reaches its peak nearly overhead on autumn evenings, as does the famous Double Cluster. Both of these objects appear as fuzzy patches to the naked eye under a dark sky.

Deep-sky highlights

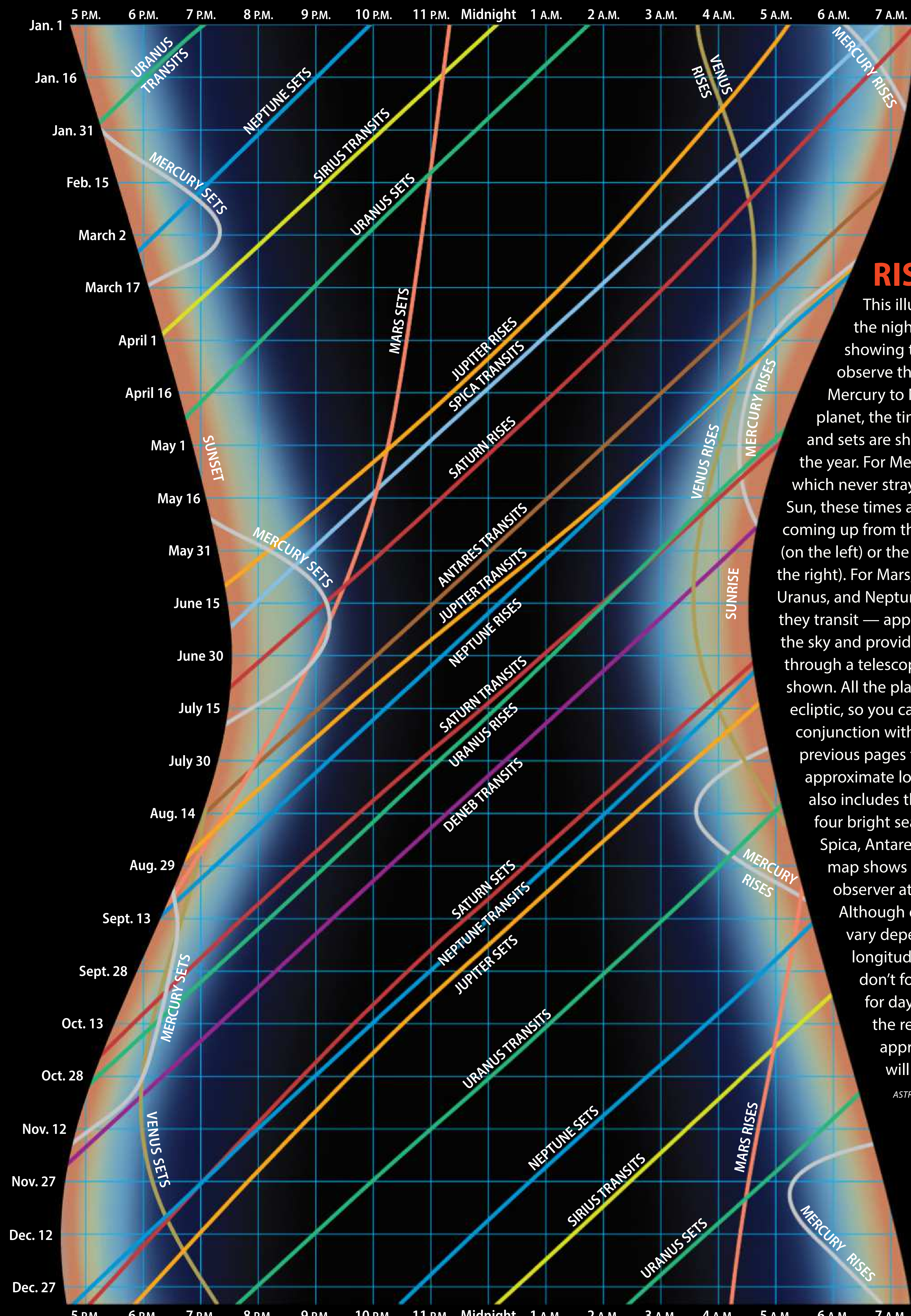
The Andromeda Galaxy (M31) is the brightest naked-eye object outside our galaxy visible in the northern sky.

The Double Cluster (NGC 869 and NGC 884) in Perseus consists of twin open star clusters. It's a great sight through binoculars.

M15 in Pegasus is a globular cluster containing hundreds of thousands of stars, many of which can be glimpsed through a medium-sized telescope.

Albireo (Beta [β] Cygni), the most beautiful double star in the sky, is made up of suns colored sapphire and gold.

Astronomy magazine



RISE & SET

This illustration presents the night sky for 2019, showing the best times to observe the planets from Mercury to Neptune. For each planet, the times when it rises and sets are shown throughout the year. For Mercury and Venus, which never stray too far from the Sun, these times appear as loops coming up from the sunset horizon (on the left) or the sunrise horizon (on the right). For Mars, Jupiter, Saturn, Uranus, and Neptune, the times when they transit — appear highest in the sky and provide the best view through a telescope — also are shown. All the planets lie near the ecliptic, so you can use this chart in conjunction with the maps on the previous pages to find a planet's approximate location. The chart also includes the transit times of four bright seasonal stars: Sirius, Spica, Antares, and Deneb. This map shows local times for an observer at 40° north latitude. Although exact times will vary depending on your longitude and latitude (and don't forget to add an hour for daylight saving time), the relative times and approximate positions will stay the same.

ASTRONOMY: RICK JOHNSON

MARTIN GEORGE describes the solar system's changing landscape as it appears in Earth's southern sky.

March 2019: Jupiter comes to the fore

Planet observers don't have a lot to look forward to on early evenings in March. The only bright solar system object is **Mars**, which appears low in the northwest as darkness falls. The Red Planet shines at a respectable magnitude 1.2 early this month and dims a bit to magnitude 1.4 at month's end.

Mars drifts eastward through Aries for most of March before entering Taurus on the 24th. On the 30th, the ruddy world passes just 3° south of the Pleiades Cluster (M45). Binoculars enhance the view, and will show the two objects in the same field of view throughout the month's final week.

A telescope, unfortunately, doesn't do much for Mars. The planet appears only 5" across and won't show any detail. We'll have to wait until 2020 before telescopic views get any better.

The planetary landscape starts to improve by late evening. In early March, **Jupiter** rises just before local midnight. It comes up nearly a half-hour earlier each week, however, and by the 31st, it pokes above the eastern horizon at 10 P.M. The planet moves eastward against the backdrop of Ophiuchus, creeping toward its border with Sagittarius. Gleaming at magnitude –2.1, Jupiter far outshines the nearby stars.

And unlike Mars, Jupiter proves to be an exceptional telescopic subject. As a child, I was thrilled with my first view of Jupiter through a small telescope, and I'm sure you will be, too. That's all the equipment you need to see its 38"-diameter disk and some atmospheric features. The planet's four bright moons also stand out through small instruments.

Next up is **Saturn**, which rises about two hours after Jupiter along with the stars of eastern Sagittarius. Like Jupiter, it moves eastward during March, but it travels at a much slower pace. The magnitude 0.6 planet climbs higher in the east as the night progresses, reaching halfway to the zenith by the time morning twilight begins.

By that time, Saturn becomes a stunning object through any telescope. Even the smallest instrument reveals the spectacular ring system. In mid-March, the rings span 36" and tilt 24° to our line of sight. Look for the dark gap of the Cassini Division that separates the outer A ring from the brighter B ring. Small scopes also reveal the planet's brightest moon, 8th-magnitude Titan, which orbits Saturn once every 16 days.

The waning crescent Moon passes in front of Saturn on March 29. Observers across southern Africa can view this occultation. From Cape Town, South Africa, Saturn's disk starts to pass behind the Moon's bright limb at 3h50m UT, with the rings beginning their disappearance shortly before. The planet reappears at the dark limb in daylight at 5h08m UT, when the Sun lies 2° above the horizon.

Brilliant **Venus** is the next planet to make an appearance. In early March, the magnitude –4.1 world lies a little more than 10° below Saturn. The gap widens rapidly, however, as Venus races from eastern Sagittarius through Capricornus and into Aquarius.

Although Venus is always the brightest planet, it currently lies far from Earth, and its distance increases steadily. This means that it presents a rather dull image through a telescope. On March 1, its disk spans 16" and appears 72 percent lit; on the 31st, it appears 13" across and the Sun illuminates 81 percent of its Earth-facing hemisphere.

Mercury passes between the Sun and Earth at inferior conjunction March 15. The innermost planet then climbs quickly into the eastern sky before dawn and becomes an easy target during the month's final week. On the 31st, it shines at magnitude 0.9 and stands 10° above the horizon an hour before sunrise. A telescope reveals its 10"-diameter disk and one-quarter-lit phase.

The starry sky

Some years ago, I had the pleasure of visiting Córdoba, Argentina. An easy flight from Buenos Aires, Córdoba is a delightful city, and the second most populous in the country. My main reason for visiting, however, was to see the Argentine National Observatory.

Argentine president Domingo Sarmiento and American astronomer Benjamin Apthorp Gould founded the observatory in the 1870s. Gould, perhaps most famous for creating *The Astronomical Journal*, was keen to observe the southern sky. He spent 15 years in Córdoba making systematic observations. These resulted in the star catalog *Uranometria Argentina*. But his work in Argentina also included a detailed study of an intriguing feature of our galaxy that came to be known as Gould's Belt.

Take a look to the north on any clear March evening and you'll notice many bright stars located well away from the plane of the Milky Way. Most notable among the stragglers are the bright members of Orion the Hunter, including the brilliant blue-white star Rigel. Gould noted that these stars seemed inclined to the galactic plane.

Gould wasn't the first to notice this asymmetry. Sir John Herschel recognized the peculiarity during his observations from South Africa's Cape of Good Hope. But Gould performed the pioneering work on the feature. This included determining its inclination to the galactic plane, which he found to be 17°.

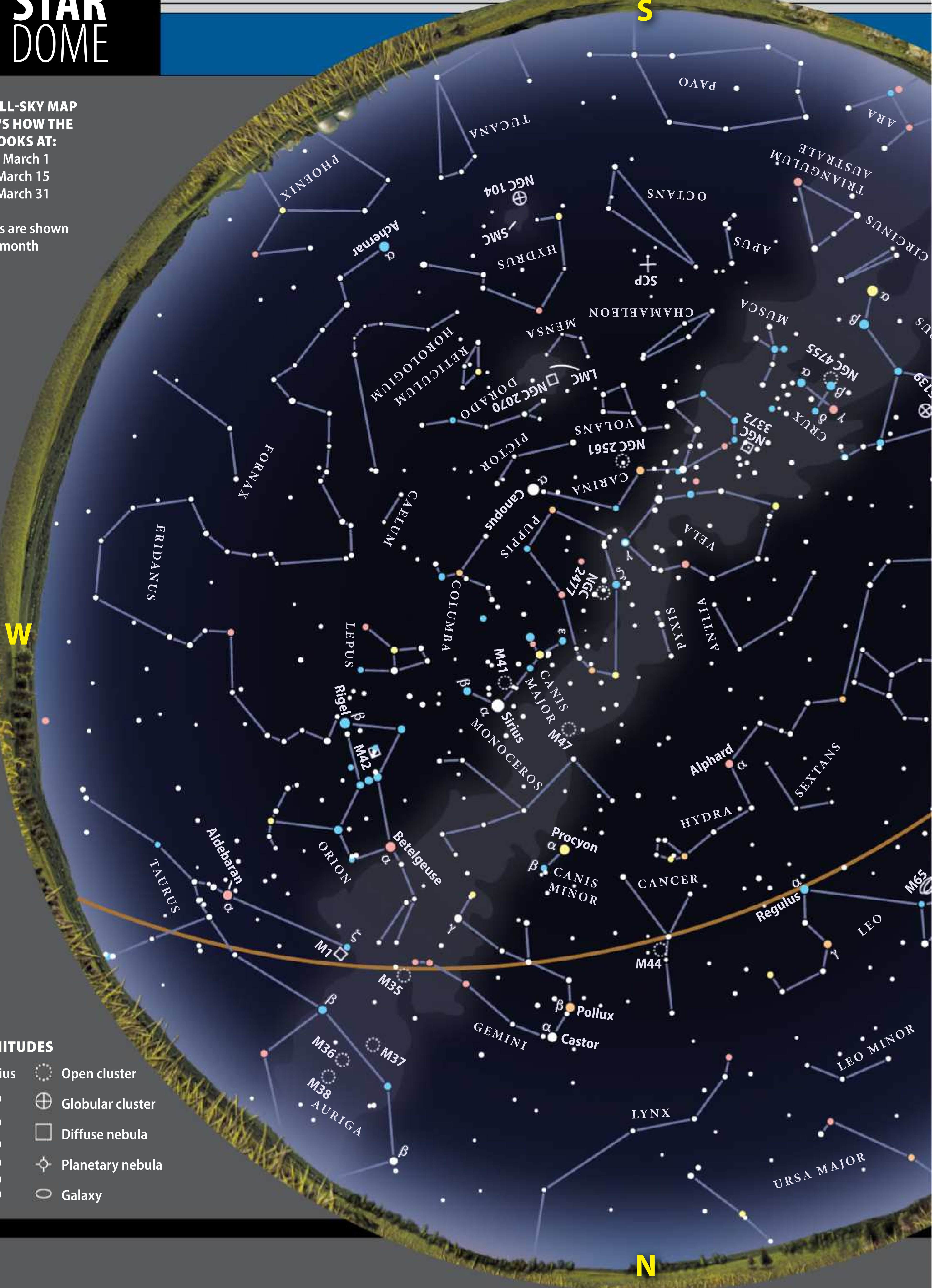
Gould's Belt has attracted the interest of many researchers since. Measurements of the belt's stars show that it is expanding. This has led several astronomers to suggest that one or more supernova explosions may be responsible. Needless to say, the belt continues to be an active area for research.

So, the next time you're away from city lights and gazing at the Milky Way, imagine yourself in the shoes of Gould and Herschel as they noted this remarkable feature of the night sky from the Southern Hemisphere so long ago.

STAR DOME

THE ALL-SKY MAP SHOWS HOW THE SKY LOOKS AT:
10 P.M. March 1
9 P.M. March 15
8 P.M. March 31

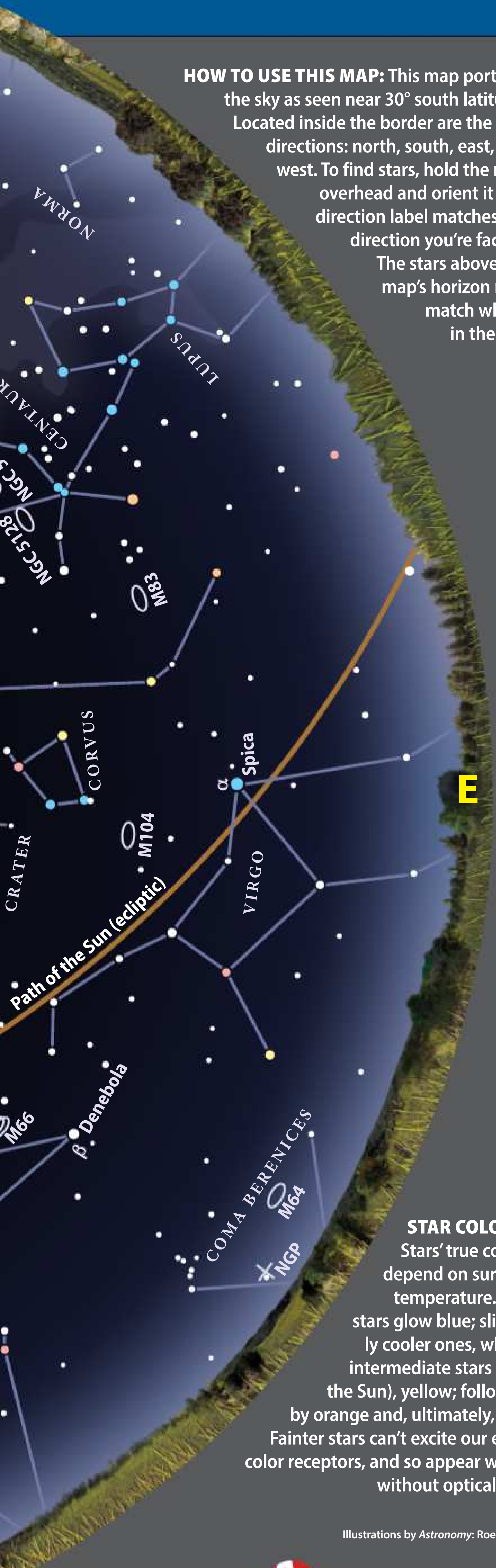
Planets are shown at midmonth



MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy



HOW TO USE THIS MAP: This map portrays the sky as seen near 30° south latitude. Located inside the border are the four directions: north, south, east, and west. To find stars, hold the map overhead and orient it so a direction label matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

STAR COLORS: Stars' true colors depend on surface temperature. Hot stars glow blue; slightly cooler ones, white; intermediate stars (like the Sun), yellow; followed by orange and, ultimately, red. Fainter stars can't excite our eyes' color receptors, and so appear white without optical aid.

Illustrations by *Astronomy*: Roen Kelly

MARCH 2019

Calendar of events

1 The Moon passes 0.3° north of Saturn, 18h UT

2 The Moon passes 0.5° north of Pluto, 4h UT

3 The Moon passes 1.2° south of Venus, 21h UT

4 The Moon is at apogee (406,391 kilometers from Earth), 11h26m UT

5 Asteroid Pallas is stationary, 2h UT

Mercury is stationary, 5h UT

6 New Moon occurs at 16h04m UT

7 Neptune is in conjunction with the Sun, 1h UT

Asteroid Vesta is in conjunction with the Sun, 22h UT

10 The Moon passes 5° south of Uranus, 4h UT

11 The Moon passes 6° south of Mars, 12h UT

14 First Quarter Moon occurs at 10h27m UT

15 Mercury is in inferior conjunction, 2h UT

19 The Moon is at perigee (359,377 kilometers from Earth), 19h48m UT

20 March equinox occurs at 21h58m UT

21 Full Moon occurs at 1h43m UT

27 The Moon passes 1.9° north of Jupiter, 2h UT

Mercury is stationary, 12h UT

28 Last Quarter Moon occurs at 4h10m UT

29 The Moon passes 0.05° south of Saturn, 5h UT

The Moon passes 0.3° north of Pluto, 12h UT

Astronomy magazine

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**